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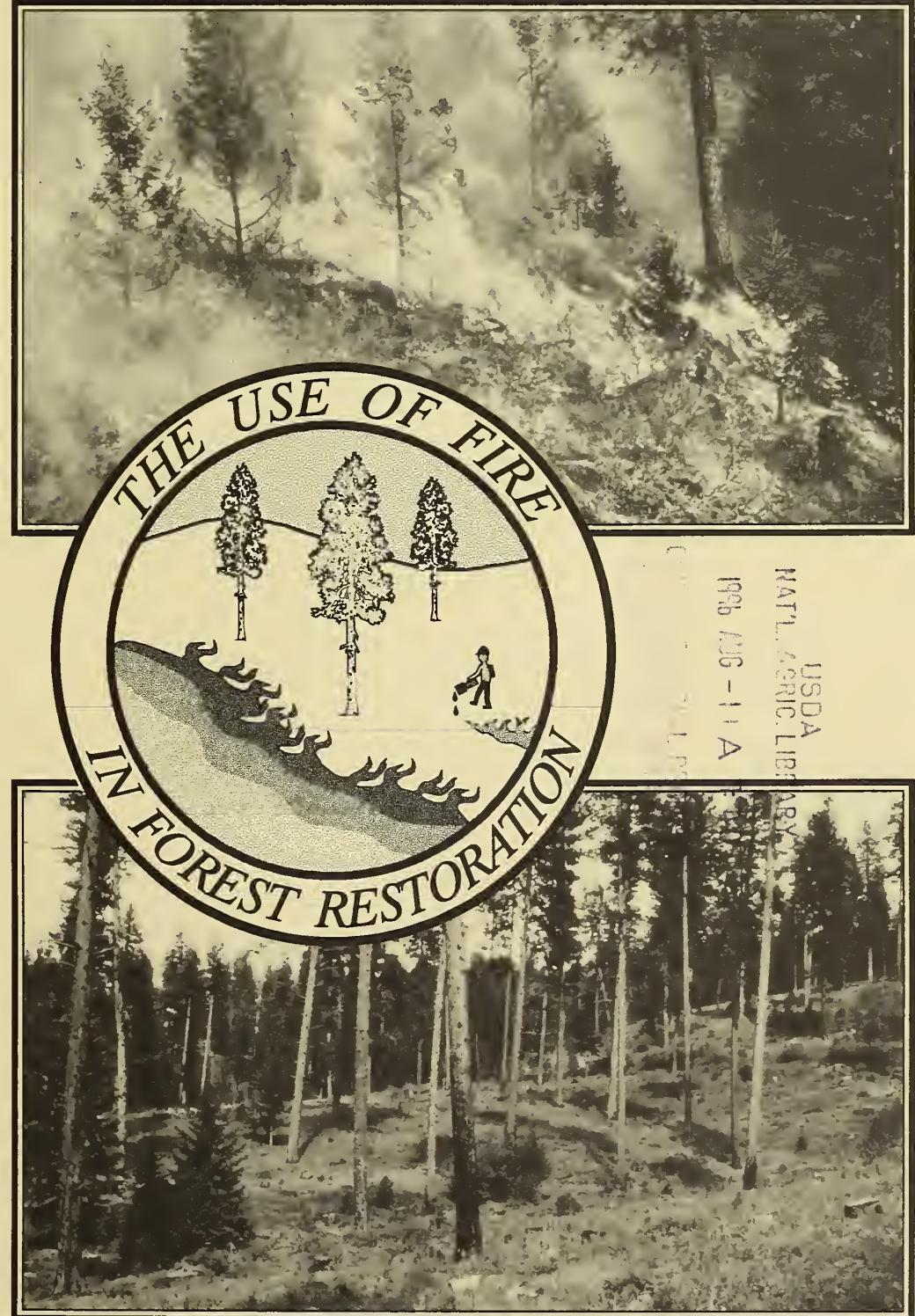
The Use of Fire in Forest Restoration

Forest Service

Intermountain Research Station

General Technical Report INT-GTR-341

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Preface

Early in 1995, the organizers of the 1995 Annual Meeting of the Society for Ecological Restoration (SER) provided us an opportunity to sponsor a general technical session dedicated to the role of fire in ecological restoration. The SER organizers also allowed us to independently develop and publish the session proceedings. The SER theme for this annual meeting was "Taking a Broader View," evoking exploration of a broader range of strategies to meet the challenges of ecological restoration. We viewed this as a unique opportunity to bring together the latest knowledge of fire as both a disturbance and restoration agent and to present it to a diverse audience of natural resource scientists, professionals, and managers.

Our general technical session, "The Use of Fire in Forest Restoration," included 24 papers that are presented here in three sections: Assessing Needs for Fire in Restoration; Restoration of Fire in Inland Forests; and Restoration in Pacific Westside Forests. In addition, Stephen F. Arno provides an introduction addressing the impetus for both this technical session and this document, and R. Gordon "Gordie" Schmidt's epilogue challenges us to consider how we can assure that the effects of fire are replicated in ecosystems in a way that is socially and environmentally successful.

This document is a synthesis of knowledge and applications of fire as an agent of both disturbance and ecosys-

tem restoration in forest ecosystems of the Northwestern United States. While we have reviewed and edited these papers for technical content and conformity to the session theme, peer review has been the responsibility of the authors. Opinions expressed are those of the respective authors and are not necessarily the opinions of the editors, or of the U.S. Department of Agriculture.

Acknowledgments

We are indebted to the Society for Ecological Restoration (Madison, WI) for sponsorship of the general technical sessions at the 1995 Annual Meeting. The conference organizers were committed to, and highly supportive of, our desire to organize, hold, and publish the proceedings from a relatively independent technical session. We are particularly grateful to Karrie Simic of the University of Washington Engineering Professional Programs staff, Claramarie Moss Kidd of Moss Environmental, and Tim White from CH2M HILL. Our thanks to Dr. David Peterson, University of Washington College of Forest Resources, who graciously moderated a portion of the session with very short notice. Our extensive edits and revisions on some of these papers have been reviewed and key-boarded by Helen Smith, Intermountain Fire Sciences Laboratory. We are fortunate and grateful for her attention to detail and organization. Lastly, thanks to all of the authors for their willingness to participate and work within our expectations and time schedules.

Table of Conversions

Parameter	Multiply this unit	By this factor	To obtain this unit
Biomass loading	megagrams per hectare (mg/ha) tons per acre (ton/acre)	0.4461 2.2417	tons per acre (ton/acre) megagrams per hectare (mg/ha)
Basal area	square feet per acre (ft ² /acre) square meter per hectare (m ² /ha)	0.2296 4.3354	square meter per hectare (ft ² /ha) square feet per acre (m ² /acre)
Mass	tons pounds	2,000 0.0005	pounds tons
Length	micrometers (μm) inches (in) meters (m) feet (ft)	0.0000394 25,400 3.2808 0.3048	inches (in) micrometers (μm) feet (ft) meters (m)
Area	hectares (ha) acres (acres)	2.471 0.4047	acres (acre) hectares (ha)

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The Use of Fire in Forest Restoration

A General Session at the Annual Meeting of the Society for Ecological Restoration

Seattle, WA, September 14–16, 1995



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Introduction



The Seminal Importance of Fire in Ecosystem Management—Impetus for This Publication

Stephen F. Arno

Fire—Agent of Change

In September 1995, the Society for Ecological Restoration (SER) held its Annual Meeting at the University of Washington in Seattle. The meeting included two dozen conferences and several symposia and field trips dealing with various aspects of applying ecological restoration on both site-specific and landscape scales. More than a thousand scientists, educators, land managers, and others interested in issues relating to ecosystem-based management attended. The keynote speaker, Professor Daniel Botkin of George Mason University, exhorted the assembly to think of the natural landscape as an everchanging "motion picture" rather than as a single idyllic frame. Botkin (1990) and other prominent ecologists have warned that environmental concerns often focus on preserving a particular successional state (single frame), such as an old growth forest, rather than maintaining a dynamically functioning ecosystem or landscape with its many successional states.

Agents of change in nature are termed "disturbances." Wildland fire is perceived by many Americans as a very "disturbing" agent of change. Although our technological society has developed the ability to delay wildland fire and to influence the frequency and severity of burning, our efforts to exclude fire are often unsuccessful in the long run and can have negative ecological effects (Agee 1993). Despite costly fire-fighting efforts, the annual area burned in wildfires has generally increased in the Western United States since the 1970's (fig. 1), an increase attributable partly to a buildup of woody fuels and partly to drought (Arno and Brown 1989; Agee 1993). Over \$1 billion was spent during 1994 for fire suppression in the United States; nevertheless, 4 million acres burned in wildfires, many of which were controlled only when it rained. Unquestionably, we need an efficient fire suppression capability, but shouldn't we also be using prescribed fire and silvicultural fuels management to restore a semblance of the natural fire process (Mutch 1994; Williams 1995)?

Reading advance announcements for the SER annual meeting spawned an idea—why not propose an associated conference highlighting fire as a component of the broader goal of restoring natural landscapes. Our proposal was accepted by SER organizers and, as a result, we hosted a

conference entitled "The Use of Fire in Forest Restoration." We are publishing authors' synopses of their conference presentations in this volume because we believe they represent a unique contribution to the understanding of fire as a component of ecological restoration in forests of Western North America.

Perceptions of Fire

During the last few years natural resource specialists have begun to support the concept of reintroducing fire in some form to fire-dependent ecosystems—those where fire played a vital role in determining composition, structure, and landscape patterns. But why did this sentiment take so long to develop? Interestingly, a century ago USDA Forest Service founder Gifford Pinchot and naturalist John Muir called fire "one of the great factors which govern the distribution and character of forest growth" (Pinchot 1899).

Pinchot, writing in National Geographic Magazine, explained that since time immemorial fire regulated the composition and structure of forests all across North America.

Total Wildfire Acreage in Eleven Western States

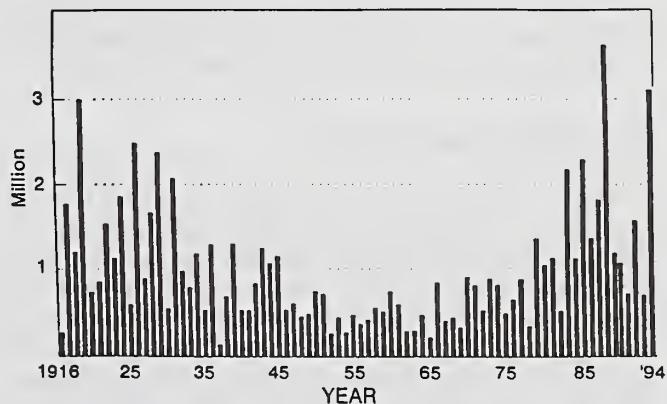


Figure 1—Total acreage burned in wildfires annually in the 11 Western States (AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY). Data prior to 1931 do not include National Park Service or Indian Reservation lands; data prior to 1926 apparently include only forested areas. (Data from USDA Forest Service Smokey Bear Reports 1916-1982 and from individual agency reports 1983-1994 compiled by Bureau of Land Management, National Interagency Fire Center, Boise, ID.)

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He recognized, for example, that the magnificent Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) forests of western Washington and western Oregon owed their existence to fire. He referred to the "creative action of forest fires" and suggested that it would be fruitful to gain an understanding of the natural role of fire.

Over the past century, great strides have been made in learning about the ecological effects of fire in wildland forests (Agee 1993). Paradoxically, application of this knowledge has been hampered by land management policies that assumed we could exclude fire from fire-dependent forests with little adverse effect (Pyne 1982). Native Americans and a few early timberland managers recognized that fire could be used in maintaining desirable forest conditions, but after 1910—following Pinchot's departure from the agency—the Forest Service rejected this concept and developed a campaign to eliminate fire from the forest (Pyne 1982). This undoubtedly seemed like an appropriate policy and few foresaw its long-term consequences.

Today, perhaps the most widely recognized example of negative effects of fire exclusion is the "forest health" problem on tens of millions of acres in the ponderosa pine (*Pinus ponderosa*) and related forests of the Inland West (Mutch and others 1993; American Forests 1995; Phillips 1995). Ironically, a government forester named Harold Weaver (1943) identified this problem more than 50 years ago and traced its roots to fire exclusion. Weaver (1943, 1967) and a few colleagues called for use of prescribed burning to restore fire to these forests, which historically burned in frequent low-intensity fires. Eventually their arguments were accepted by many foresters and ecologists (Pyne 1982). By the late 1970's even Congress's General Accounting Office had recognized the futility of attempting to eliminate fire in the wildlands of Western North America. As a result, Federal agencies adopted policies that broadened and revised their mission as "fire management"—not just fire control. This included prescribed burning on the landscape as well as the traditional suppression of unwanted fires (Nelson 1979).

Devising Restoration

Despite considerable knowledge and support for reintroducing fire into wildland forests, major obstacles confront land managers (Mutch 1994). Funding for prescribed burning and silviculture to reduce fuel accumulations has traditionally been subservient to funding availability for suppressing wildfires. Fuels treatment work must be paid for from the annually appropriated budget, while suppression funding is covered by an "emergency" account that is perceived by some to be unlimited. Land managers are held responsible for the smoke emissions produced by prescribed burning, and they can also suffer career setbacks when even carefully planned and executed burns escape control due to circumstances beyond their control. Conversely, management that attempts to exclude fire from an ecosystem and ultimately results in damaging wildfires is seldom questioned. Moreover, land managers are seldom blamed for high costs of fighting wildfires in built-up fuels or for severe smoke or damages such fires produce.

The severe wildfire seasons in northern California and Oregon in 1987, in Yellowstone Park, and the Northern Rocky Mountains in 1988, and throughout much of the West in 1994 have made it clear that fire cannot be excluded from fire-dependent ecosystems. On the other hand, because of altered fuels and the need to protect adjacent private lands, developed areas, and commercial forests, fire cannot be fully restored to its historic character—except perhaps in a few of the largest wilderness areas (Brown and others 1994). Nevertheless, fuels management and prescribed fire could be used to recreate an acceptable semblance of the natural fire process in many natural areas (Arno and Brown 1989). Also, the severity of wildfires could be reduced by accomplishing fuel treatments in strategically selected areas having the greatest probability of success (Williams 1995).

Role of These Proceedings

Several papers in these proceedings give suggestions and examples for restoring the fire process in various forest types representing different natural fire regimes. Three general types of fire regimes apply to North American forests (Brown 1995):

1. A "nonlethal understory fire regime" of frequent low-intensity fires was common in the ponderosa pine and Oregon oak (*Quercus garryana*) types, as discussed in some of the papers in this volume.

2. At the opposite extreme, a "stand-replacement fire regime" is characterized by lethal fires at long intervals, such as in the high-elevation lodgepole pine (*Pinus contorta* var. *latifolia*) type in the greater Yellowstone Park ecosystem.

3. Intermediate to these is the "mixed severity fire regime" that was once widespread in Western North America. Here, fire burned with variable severities in an intricate mosaic, killing many trees but allowing others to survive. Survivors were often fire-resistant species and larger trees with thicker bark and higher crowns resistant to burning.

Fire exclusion can result in conversion of a nonlethal fire regime to a mixed-severity or stand-replacement regime (fig. 2), with accompanying changes in forest composition and natural biodiversity (Agee 1993).

Presentations contained in these proceedings explain principles of fire ecology and landscape pattern in Western North American forests, especially in Session I (Assessing Needs for Fire in Restoration).

Session II (Restoration of Fire in Inland Forests) concentrates on actual examples of fire restoration in inland forests where such practices have been underway for several years.

Session III (Restoration in Pacific Westside Forests) brings out the seldom discussed subject of fire restoration in forests west of the Cascade Crest. Here millions of acres are being "preserved" as natural areas under management that excludes the essential creative process that Pinchot and Muir recognized a century ago.

Humans will have to make a leap in both ecological knowledge and philosophical understanding of our relationship to nature in order to attain the lofty goals implied by the

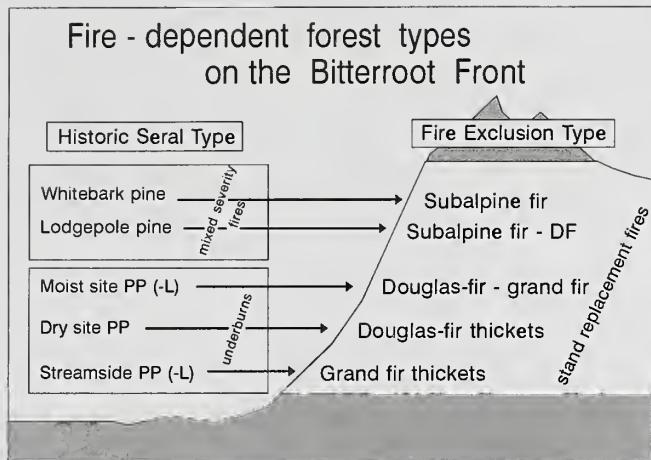


Figure 2—A schematic representation of forest zonation on the Bitterroot Range west of Stevensville, MT. The dominant tree species and corresponding fire regimes are shown for both historic (pre-1900) and modern periods. DF = interior Douglas-fir; L = western larch; PP = ponderosa pine.

terms ecological restoration and ecosystem management. In many North American ecosystems, recreating a semblance of the natural fire process will be at the heart of ecological restoration.

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Assessing Needs for Fire in Restoration



Restoring Fire to Ecosystems: Methods Vary With Land Management Goals

Robert W. Mutch
Wayne A. Cook

Periodic forest, grassland, and shrubland fires are part of the natural environment—as natural and vital as rain, snow, or wind (Heinselman 1978). Evidence of past fires is found in charcoal layers in lakes and bogs, and in the fire-scarred cross sections of trees. Recurring disturbances by fire are essential to the functioning of many ecosystems, termed “fire-dependent,” that are found throughout North America (Heinselman 1978). Many examples are available to describe how fire affects the functioning of ecosystems, such as influencing plant succession, fuel accumulations, structure and composition of vegetation, insect and disease populations, nutrient cycling, productivity, diversity, and habitats for wildlife.

Kilgore and Heinselman (1990) highlighted fire’s historical role as a fundamental disturbance process in their classification of “continental fire regimes.” They described a natural fire regime as the total pattern of fires over time that is characteristic of a region or ecosystem. They also defined fire regimes as to fire type and intensity, typical fire sizes and patterns, and fire frequency, or length of return intervals in years (Agee, this proceedings). The noteworthy aspect of continental fire regimes is that few plant communities in North America occur where fires historically were rare or absent. In other words, most ecosystems in the United States evolved in environments where wildland fires occurred regularly, establishing fire as a process that affects many ecosystem functions. The application of prescribed fire, for many different purposes, attempts to mimic the diverse effects within the natural role of fire. However, prescribed fire has not been used on a scale adequate for sustaining the productivity of fire-dependent ecosystems.

After reviewing some prescribed fire accomplishments in the United States, we will identify several pending recommendations that could modify the future of prescribed fire.

Fire Science and Fire Prescriptions

Lightning, volcanoes, and people have been igniting fires in wildland ecosystems for millennia. The current emphasis on managing ecosystems highlights interactions between disturbance processes and ecosystem functions. Land managers and fire managers need to understand the historic

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frequency, intensity, and the areal extent of past fires. Such knowledge provides a frame of reference for prescribing appropriate management practices on a landscape scale.

Many studies have reported on the historical occurrence of fire throughout the world. For example, Swetnam (1993) submitted a report documenting 2,000 years of fire history in giant sequoia (*Sequoiadendron giganteum*) groves in California. He found that frequent small fires occurred during a warm period from about 1000 to 1300 A.D. The less frequent but more widespread fires occurred during cooler periods from about 500 to 1000 A.D. and after 1300. Swain determined from lake sediment analysis in the Boundary Waters Canoe Area that tree species and fire had interacted in complex ways for more than 10,000 years (Swain 1973). A great deal of scientific information provides details on the many effects of wildland fire on ecosystems. This knowledge allows managers to develop prescribed fire program prescriptions for individual fires and to achieve a variety of resource management objectives.

How widespread is the use of prescribed fire in the United States today? Federal land management agencies manage more than 600 million acres. A recent survey showed that prescribed fire in the United States is used to treat about 5 million acres annually (Ward and other 1993). More than 3.5 million acres, or 70 percent of all prescribed burning, was in the Southeast. Purposes for using prescribed fire included hazard reduction, silviculture, vegetation management, range improvement, wildlife habitat improvement, and “other” reasons, including watershed management, pest control, disease control, and research. A category apparently not covered in the survey was prescribed natural fire in National Parks and wildernesses. Many National Parks and wildernesses across the United States have approved plans that allow lightning fires to burn when they have met all identified prescription criteria. Some of these individual prescribed natural fires have been 10 to 15 thousand acres or greater in the Rocky Mountains (Kurth, this proceedings; Parsons and Botti, this proceedings).

Decline of Ecosystem Health

Many ecological indicators from the Southeast to the West present an alarm of declining forest health. Attempts to exclude fire since the early 1900’s, combined with drought and epidemic levels of insects and diseases, have now produced extensive forest mortality. Gray (1992) called attention to a forest health emergency in the Western United States. He cited widespread forest mortality that has occurred across millions of acres in eastern Oregon and Washington and similar problems in forests of Utah, Nevada,

California, and Idaho. The historical norm in long-needed pine forests (ponderosa pine, etc.) throughout the west was for frequent low-intensity surface fires. Now, dense stands and heavy fuel accumulations are setting the stage for high-intensity crown fires.

Since the 1980's, large wildfires in dead and dying western forests have accelerated the rate of forest mortality, threatening people, property, and natural resources (Mutch 1994). These wildfires also produce large amounts of smoke. More than 50 years ago, Weaver (1943) reported that the "...complete prevention of forest fires in the ponderosa pine region of the Pacific slope has certain undesirable ecological and silvicultural effects...conditions are already deplorable and are becoming increasingly serious over large areas." Cooper (1961) stated that "fire has played a major role in shaping the World's grassland and forests. Attempts to eliminate it have introduced problems fully as seriously as those created by accidental blazes."

Some have said that we have been engaged in a grand ecological experiment with this attempt to exclude fire from fire-adapted ecosystems. Fire exclusion is a problem even in the southeastern United States where the majority of prescribed burning is conducted because the scale of such burning is very inadequate (Landers and others 1995). About 90 million acres of longleaf pine (*Pinus palustris*) existed during the late nineteenth century in the Southeast. Due in part to the absence of fire, today's stands occupy only about 2.9 million acres.

Our Prescribed Fire Future

Use of prescribed fire along with other management practices is part of the solution in sustaining healthy forests to benefit people. Developing strategies for reintroducing fire on a landscape scale will require overcoming many barriers imposed on land managers either directly or indirectly. The present strong fire suppression programs are essential, but must be complemented by equally well supported prescribed fire programs to overcome the following barriers to burning: air quality, water quality, threatened and endangered species, visual quality, funding, and risks.

In May of 1995, the Forest Service released a comprehensive report with findings and recommendations to help the fire management program overcome major obstacles (USDA Forest Service 1995). Five key recommendations were set forth in this report:

1. Restoring ecological processes: Increase mechanical (for example, thinning) and prescribed fire treatments to 3 million acres a year (five times the current levels) in fire-dependent ecosystems by the year 2005. Emphasize the appropriate ecological recovery efforts on recently burned wildfires.

2. Sustaining fire-dependent ecosystems: Establish a multi-funded, interdisciplinary account for restoration and maintenance of fire-dependent ecosystems by the year 2005. Develop a workforce capable of restoring these ecosystems.

3. Forest land management planning: Address the ecological basis for fire across the landscape. Fully display the long-term consequences anticipated as a result of both fire use and attempted fire exclusion. Establish prescribed fire objectives and assess fire consequences within the land management planning process.

4. Wildland/urban interface: Renegotiate agreements with state and local cooperative fire agencies at the wildland/urban interface to clarify protection responsibilities. Phase out the Forest Service as a primary protection agency in suburban and developing rural areas.

5. Reorienting the workforce: Move toward preparing 75 percent of the total workforce to be trained, qualified, and available to support fire management by the year 2000.

With this strategy it is apparent that the Forest Service fire management program is positioning itself to greatly improve its ability to restore fire in National Forests.

Current Solutions

Some breakthroughs in providing more latitude for expanding prescribed fire programs are apparent. For example, the state of Florida has enacted innovative legislation that provides liability protection for prescribed burning. In Oregon, a cooperative program among Federal and state agencies is developing a fire emissions tradeoff model (USDA Forest Service 1993) that predicts smoke emissions from prescribed fires and wildfires in the Blue Mountains. The goal of this effort is to design a prescribed burning and fuel treatment program that reduces overall smoke emissions (Ottmar, this proceedings).

The Western States Air Resources Council (WESTAR), a nonprofit association of air quality agencies in the 14 western states, has drafted an initiative entitled "Forest Health Initiative to Restore Ecosystems" (FIRES) to address both technical and policy-related issues for forest health and air quality. The goal of the 3 year project is to bring together a broad-based consortium to develop regional solutions based on science and to balance the needs of forest health while protecting air quality. FIRES will respond to the concerns of Congress, the western state air regulators, Federal land management agencies, and the public (WESTAR 1994). These initiatives help to provide more latitude for prescribed fire programs to evolve in a more supportive environment.

Because many stands are now excessively dense and contain many dead and dying trees (Mutch and others 1993), salvage logging, thinning, and partial cutting may be necessary before initiating extensive prescribed burning programs (Arno and others, this proceedings). The larger trees of fire-resistant species, such as ponderosa pine and western larch, should be retained, and understory trees should be largely removed.

In other situations, resource managers and fire managers have conducted some landscape scale prescribed burns, including the following examples from 1993 and 1994: a 16,000 acre burn on the Santa Fe National Forest; a 700 acre prescribed fire for wildlife winter range on the Lolo National Forest; a 1,000 acre burn on the Boise National Forest; a 6,000 acre prescribed fire on the Umatilla National Forest; and a 5,000 acre aerially ignited crown fire on the Tetlin Wildlife Refuge in Alaska (Vanderlinden, this proceedings).

Conclusions

Resource management agencies, regulatory agencies, politicians, and society have a challenging opportunity to carry

out meaningful ecological restoration programs. These must be at a scale large enough to sustain the health of fire-adapted ecosystems, benefiting people, property, and natural resources. Society needs to move away from litigation and the courtroom as strategies for managing natural resources. Instead, we should employ the available scientific knowledge and management experience for managing wildland ecosystems more in harmony with disturbance factors.

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Fire Regimes and Approaches for Determining Fire History

James K. Agee

Fire has been an important evolutionary influence in forests, affecting species composition, structure, and functional aspects of forest biology. Restoration of wildland forests of the future will depend in part on restoring fire to an appropriate role in forest ecosystems. This may include the "range of natural variability" or other concepts associated with fire as a disturbance factor. Yet fire on the forested landscape has not been a constant in either space or time. Its frequency, intensity, seasonality, extent, and other characters—collectively known as a fire regime—varied considerably across western forest landscapes. A series of techniques can be used to understand this history, and accurate interpretation depends on using the best fire history technique for a given fire regime. The following synopsis of these techniques is based on a more detailed explanation provided in Agee (1993).

Fire Regimes

There is no magical way to define a fire regime, as there are myriad combinations of fire frequency, intensity, etc., that could be formed. Natural fire regimes are usually defined in a historical sense, typically restricted to the pre-1900's, but they clearly are natural in the sense of incorporating effects of indigenous cultures—we cannot, in most cases separate out the human component of historical fire regimes. A generalized system of classifying fire regimes, given the wide range possible, is to define fire severity categories of high, moderate, and low. Low severity fire regimes typically had frequent, low intensity fires. High severity fire regimes had infrequent but stand-replacing fires, and the moderate severity fire regimes (also called mixed severity) had complex combinations of high, low, and moderate severity fires.

The evidence left behind for reconstruction of fire regimes will vary by fire regime. In the low severity fire regimes, fire scars will often be created on residual trees, so that the year, and sometimes the season, of a fire can be determined. In moderate severity fire regimes, with longer fire return intervals, some scars are likely to heal over, and multiple age classes of fire-induced tree regeneration are likely to result. In high severity fire regimes, few survivors are left, and the most common evidence, besides presence of charcoal, are even-age stands (which themselves can have substantially varying age ranges). The implications for fire history are that the techniques for reconstructing fire history must vary by fire regime because of the nature of the evidence left behind.

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Fire Histories

Two primary types of fire history reconstructions are made: those for "point frequency" estimates, and those for "area frequency" estimates. Point frequency estimates attempt to reconstruct the fire history at a point, and are usually used in low severity fire regimes. Area frequencies, as the phrase implies, deal with fire at more of a landscape level, and are used in those fire regimes of higher severity. These differences are very important for interpreting past fire history and planning for fire restoration. Different techniques can derive widely varying fire return intervals.

Point Frequencies

The use of point frequencies depends on sampling fire scars. Slabs from stumps or live trees containing the annual ring-fire scar record are usually removed with chain saws. Samples can be removed using increment borers if there is just one scar, but generally this technique is used only when slab removal is not possible. Samples with many fire scars (sometimes up to 30 scars) can be found and provide the best record. Samples are taken to the laboratory, sanded, and the sections are carefully cross-dated. Cross-dating is extremely important, because the fire years recorded on nearby samples may sometimes be combined to provide a more complete record of fire near a given point. It is important that fire years be accurately identified.

It is rare that any tree will contain the entire record of fire over its lifetime; although a tree is the best "point" on the landscape, it is usually not the best sample unit to use to derive a "point estimate" of fire. Usually the combination of cross-dated records from two or more closely spaced trees are used. Each sample tree is itself a point sample, and as the number of trees whose records are combined grows, two things usually happen: the fire record becomes more complete, so that the fire return interval becomes shorter; and the point frequency tends to become an area frequency as the area over which records are combined expands. Over how large an area can fire scar records be combined? This is a judgment call, but for most stand-level applications several hectares is the maximum recommended.

Steve Arno's work in the Rocky Mountains clearly shows the influence of increasing area on fire return interval (Arno and Petersen 1983). And a practical example was provided by Joyce Bork (1985) in Oregon. Harold Weaver had sampled individual trees (points) in the 1950's and found an 11-16 year fire return interval. Bork, I was told, had found a 4 year fire return interval in the same vegetation type. Actually, she described her data carefully by area, and my informants had only reported the 300 acre (125 ha) fire return interval of 4 years. If expressed as point samples on individual trees, her data were more variable than Weaver's, but as he sampled only the best specimens, his "point" data are probably most

equivalent to her "plot" average of 11 years. Thus, careful interpretation of fire history data is very important.

Area Frequencies

Fire history techniques based on aggregation of stand ages across the landscape (thus the term area frequency) are used in moderate and high severity fire regimes, as fire-scarred trees are either less commonly or not commonly found. Two primary techniques are used here: natural fire rotation, and the fire cycle.

The natural fire rotation technique is more applicable to Western United States forests. Natural fire rotation is a simply calculated statistic: it is the time period divided by the proportion of the study area burned in that time period (which can exceed 1). For example, if in a 100 year period 40,000 acres of a 50,000 acre area burn, the natural fire rotation is 125 years ($100/[40,000/50,000]$). The major problem with natural fire rotation is that all previous fire events must be reconstructed, and as time goes by, older events are obscured by younger ones. Usually, the record for the distant past includes only the major fire events.

Fire events are defined on the basis of age classes of seral tree species likely to have regenerated following a disturbance: for example, Douglas-fir (*Pseudotsuga menziesii*) in a moist, west Cascade landscape or the serotinous-coned lodgepole pine (*Pinus contorta*). Fire is assumed to be the primary disturbance on the landscape. For event reconstruction, a set of rules have to be defined, such as "two stands of the same, older age, separated by a stand of younger age, are assumed to have been part of a single event, the evidence of which was destroyed by the younger-aged event."

Most landscapes exhibit substantial variability in fire occurrence, so that a single natural fire rotation value (for example, 162 years) is not very meaningful. Once the reconstruction of fire events is complete, the record can be disaggregated by time (century by century), aspect (usually south aspects burn most frequently), and forest types in the study area, if these have also been geographically identified. Separate return intervals for low versus moderate and high severity fires can be calculated, too, as has been done by Morrison and Swanson (1990) in the central Oregon Cascades. Variability can also be described by Poisson distributions, evaluating the probability of 0, 1, 2, etc., fires in grid cells across study areas. This may be important in defining fire refugia (grid cells with few occurrences) or fire-dependent vegetation (grid cells with many occurrences) in a heterogeneous landscape.

Models

Mathematical models such as the Weibull have been used with success in the high severity fire regimes of the boreal forest and Canadian Rockies (Johnson and Van Wagner 1985), but at scales below about 125,000 acres (50,000 ha) this variety of model has not been used with success in western U.S. forests. A special case of the Weibull function, the negative exponential (where flammability of a forest stand remains constant with age), was first used to recalculate the natural fire rotation for the Boundary Waters Canoe Area, and found shorter fire return intervals. A nice aspect of these models is the use of current age class data so that reconstructions of past fire events is not needed. However, flammability by stand age has to be a monotonic function: increasing,

decreasing, or remaining constant over stand age. Fire has to strike randomly across the landscape—rare in our forested western mountains. While the natural fire rotation technique has been criticized as a form of "storytelling," the use of models such as the Weibull can be just a more elaborate storytelling framework if not properly applied.

Applying Forest History Knowledge

If the use of fire for forest restoration expands on our western landscapes, among the most critical questions will be "where, how frequently, how intense, and when it should be applied." Fire history studies can provide answers in an historical context. These studies may not result in firm direction for the future, but can provide an accurate picture of how forest ecosystems interacted with fire in the past. A note of caution should be injected into the "natural range of variability" paradigm as a model for future management of disturbances like fire.

First, the range may be so broad as to be meaningless as a guide for management: almost any fire outcome might be acceptable in this situation.

Second, we are not dealing with the ecosystems of historical times. Even "natural" areas are surrounded by severely manipulated landscapes (at least in terms of fire exclusion). There are endangered species "fine filter" issues that were not significant in historical landscapes. Introduced plants are more common and often well adapted to disturbances. A "desired future condition" may require alteration of the natural range of historic fire variability, concentrating at one end of the spectrum or another. When attempts are made to define this spectrum, complexity emerges as a key characteristic. There are ranges of fire frequency, intensity, extent, seasonality, and synergism with other disturbances like insects, disease, and windthrow. Across the forest landscape, fire regimes vary, and fire histories vary; such data must be carefully collected and analyzed to provide a meaningful historical template. How that template is used in future management is a judgment call that involves far more than fire regimes and fire history.

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Coarse-Scale Restoration Planning and Design in Interior Columbia River Basin Ecosystems: An Example for Restoring Declining Whitebark Pine Forests

Robert E. Keane
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During the last 2 years, many people from numerous government agencies and private institutions compiled a scientific assessment of the natural and human resources of the Interior Columbia River Basin (Jensen and Bourgeron 1993). This assessment is meant to guide the development of a coarse-scale Environmental Impact Statement for all 82 million hectares comprising the Interior Columbia River Basin (fig. 1). A myriad of spatial data products has been generated from this immense effort, including a wide variety of coarse-scale GIS data layers that describe historical, current, and future Interior Columbia River Basin environmental and vegetation conditions. These spatial data products can be valuable for planning ecosystem restoration activities at multiple scales. Presented in this paper is a proposed strategy for the incorporation of these coarse-scale data layers into the planning and design of restoration projects within the Interior Columbia River Basin. An application of this approach is also presented for a declining fire-dependent vegetation type—the whitebark pine (*Pinus albicaulis*) ecosystem.

Interior Columbia River Basin Scientific Assessment

After the Timber Summit held in Seattle, Washington, in May 1993, President Clinton directed the USDA Forest Service and the USDI Bureau of Land Management (BLM) to develop a scientifically sound, ecosystem-based strategy for the management of Federal forest lands in the Interior Columbia River Basin. The Chief of the Forest Service and the Director of the BLM further directed that a comprehensive ecosystem management framework and assessment be completed for all Forest Service and BLM lands in the Columbia River Basin (Jensen and Bourgeron 1993). This scientifically-based appraisal, called the Interior Columbia River Basin Scientific Assessment, was started in the winter of 1994 and was largely completed by the spring of 1995.

The Interior Columbia River Basin scientific assessment yielded an abundance of information that spatially describes many Columbia River Basin resources. These are databases,

spatial data layers, and simulation models. Nearly all data layers in the coarse-scale assessment were created at a 1 km^2 pixel resolution. Ecological attributes were mapped at the same precision across all ecosystems and across the entire extent of the Interior Columbia River Basin (that is, continuous or "wall-to-wall" coverage). When describing landscape ecology, emphasis was put on mapping those mechanisms that control Interior Columbia River Basin ecosystems rather than ecosystem traits, so most data layers describe ecosystem process rather than ecosystem state. An ecological process would be an exchange of energy within the system while an ecosystem state is a current description of an ecological condition. A detailed discussion of some general Interior Columbia River Basin data sources are provided in Keane and others (1995b). Although there are over 200 coarse-scale data layers developed specifically for the Interior Columbia River Basin scientific assessment, this paper will discuss only those data layers used in a sample analysis for whitebark pine ecosystems.

Biophysical Environment

Spatial data layers for temperature, precipitation, and radiation were simulated by Thornton and Running (1995) using an extension of the weather extrapolator MTCLIM

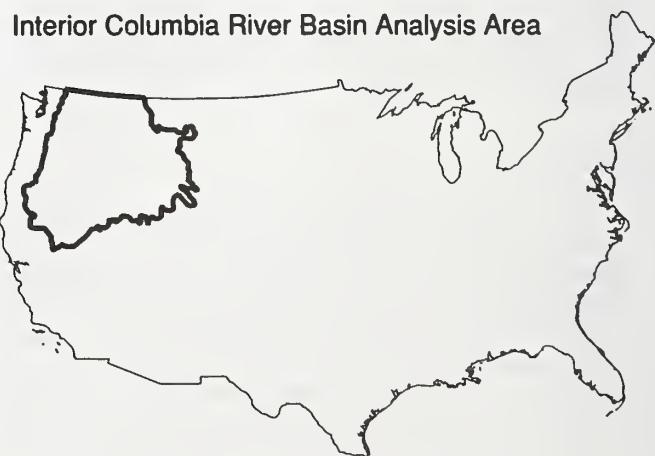


Figure 1—Geographic distribution of the analysis area for the Interior Columbia River Basin Scientific Assessment.

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(Hungerford and others 1989) called MTCLIM-3D. Elevation, aspect, and slope were calculated from a digital elevation model (DEM) provided by the Defense Mapping Agency. Parent material and other geological attributes were provided by the U.S. Geological Survey.

Vegetation

Three current and three historical data layers describing Interior Columbia River Basin vegetation were used in this paper:

1. The Current and Historical Potential Vegetation Type (PVT) Map. A potential vegetation type identifies a biophysical setting that could conceptually support a unique climax plant community. Each PVT is comprised of a group of similar habitat types or plant associations (Daubenmire 1968), and these groups were developed at a series of workshops attended by scientists and land managers. Biophysical settings were mapped from elevation, aspect, slope, and soil characteristics by geographical and ecological region (Reid and others 1995). The final PVT Map was derived by assigning coarse-scale potential vegetation types to biophysical settings based on temperature, moisture, and soils criteria. The PVT Map is roughly the same for historical and current conditions except for urban, agricultural, and industrial areas.

2. Current and Historical Cover Type Maps. The Current Cover Type Map was based on a land cover characteristics data base developed by Loveland and others (1991, 1993) from broad-scale, time series satellite imagery. Hardy and Burgan (1995b) reclassified this map to display the distribution of major forest (Eyre 1980) and range (Shiflet 1994) cover types across the Interior Columbia River Basin. Losensky (1994) developed the Historical Cover Type Map from archived maps, publications, and photos. This map portrays vegetation conditions at approximately the turn of the century (circa 1900).

3. Current and Historic Structural Stage Maps. The current Structural Stage Map was created from fine-scale data layers using discriminant analysis statistical techniques. The Historical Structural Stage layer was generated stochastically based on historical records of structural stage by cover type by county (Losensky 1994).

All vegetation data layers were then modified for input to the vegetation dynamics simulation model CRBSUM (Keane and others 1995a). This involved ensuring agreement between vegetation types across all maps. For example, all ponderosa pine cover types were removed from whitebark pine PVT's. Additional information on these data layers and the model can be obtained in a variety of impending publications summarized in Keane and others 1995b.

Fuels and Fire

Spatial descriptions of fuels and fire effects were generated by linking an extensive data base developed by Hardy and Burgan (1995a) with the cover type and structural stage data layers. A coarse-scale fire regime map was created by Morgan and others (1995) to describe severity and frequency

of fire across the entire Interior Columbia River Basin for both historical and current conditions.

Simulation Models

Two simulation models were developed for the Interior Columbia River Basin scientific assessment to predict landscape changes in vegetation cover and structure over time as a result of disturbance and succession. CRBSUM is a spatially explicit, deterministic model with stochastic properties (Keane and others 1995a). It simulates vegetation dynamics using a multiple pathway approach that integrates the effects of disturbance on successional development (Noble and Slatyer 1977). The Vegetation Dynamics Development Tool (VDDT) is essentially the same as CRBSUM but is not spatially explicit (Beukema and others 1995). It was developed to efficiently design successional pathways and quantify disturbance parameters for CRBSUM simulation. Both models simulate disturbance as a stochastic event, and the probabilities change by management scenario.

The Declining Whitebark Pine Ecosystem

Whitebark pine (*Pinus albicaulis*) is an important tree species in upper subalpine forests of the northern Rocky Mountains and northern Cascades (Schmidt and McDonald 1990). A rapid decline in whitebark pine has occurred during the last 30 years as a result of three interrelated factors: (1) epidemics of mountain pine beetle (*Dendroctonus ponderosae*); (2) the introduced disease white pine blister rust (*Cronartium ribicola*); and (3) successional replacement by shade-tolerant conifers, specifically subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana*) probably as a result of fire exclusion policies of the last 60-80 years (Kendall and Arno 1990; Keane and Arno 1993; Keane and others 1994).

Whitebark pine benefits from fire because it is able to survive low severity fires better than its competitors (Arno and Hoff 1990). Also, after large, stand-replacement fires, it readily recolonizes because its seeds are transported from distant stands and cached in the soil by Clark's nutcrackers. The nutcrackers can disperse whitebark pine seeds up to 100 times further than wind can disperse seeds of subalpine fir and spruce (Hutchins and Lanner 1982).

Integrating Coarse-Scale Data Into Mid-Scale Planning

This paper presents a scheme to integrate Interior Columbia River Basin coarse-scale data layers into mid-scale or project level restoration planning and design. This strategy is presented as a four step approach using the declining whitebark pine ecosystem of the Bob Marshall Wilderness Complex, Montana, USA to illustrate how this procedure and the Interior Columbia River Basin data can be used to plan restoration activities. The Bob Marshall Wilderness Complex consists of approximately 520,000 hectares or

about 0.6 percent of the Interior Columbia River Basin with about 40 percent of the Bob Marshall Wilderness Complex composed of whitebark pine forests in the middle to advanced stages of decline due to blister rust and fire exclusion (Keane and others 1994). Only a few of the Interior Columbia River Basin data sources are used to illustrate this approach, but many more data layers and models are available to help guide restoration planning (see Keane and others 1995b).

Step 1: Describe the Ecosystem

Any mid-scale restoration plan should contain a detailed description of ecosystem processes and their associated characteristics to help identify the appropriate mechanisms or states to restore. The Interior Columbia River Basin information can be used in this description to identify several important elements, such as geographic context, major ecological processes, and related management issues (table 1).

Geographic Context—The importance, distribution, and status of the damaged ecosystem to be restored can be

spatially described with the Interior Columbia River Basin PVT, Cover Type, and Structural Stage data layers. For example, a GIS query of vegetation layers show two PVT's could support whitebark pine: (1) Spruce-Fir Harsh PVT (SF Harsh PVT; upper subalpine climax spruce and subalpine fir types on harsh, cold and xeric sites) and (2) Whitebark Pine/Alpine Larch PVT (WBP/AL PVT; high elevation mosaic of whitebark pine and alpine larch climax types).

Two Interior Columbia River Basin cover types contained whitebark pine as a dominant species based on the plurality of basal area: (1) Whitebark Pine (WBP CT) and (2) Whitebark Pine/Alpine Larch (WBP/AL CT). The whitebark pine forests of the Bob Marshall Wilderness Complex currently account for approximately 10 percent of all Interior Columbia River Basin whitebark pine forests, and comprised about 8 percent of the pre-1900 Interior Columbia River Basin landscape (table 1). So, although whitebark pine has been declining across the Interior Columbia River Basin, it has remained at near-historical levels in the Bob Marshall Wilderness Complex, indicating the high importance of the Bob Marshall Wilderness Complex whitebark pine forests in the Interior Columbia River Basin.

Ecological Processes—A spatial analysis of the causal mechanisms that control damaged ecosystems is needed so that restoration techniques can be designed to mimic these critical ecosystem processes. Important process relationships for the Bob Marshall Wilderness Complex are compared with their average across the entire Interior Columbia River Basin in table 2. These data indicate a wetter and warmer whitebark pine habitat in the Bob Marshall Wilderness Complex. In some vegetation types, such as ponderosa pine, Interior Columbia River Basin wildfires are more lethal today than they were at the turn of the century 1900 (Agee 1993), but the Bob Marshall Wilderness Complex seems to have maintained much of its pre-1900 fire regime.

Successional processes can be characterized by comparing the historical and current Structural Stage data layers (table 3). Structural stages are defined by the stand development phases rather than dimensional characteristics of trees (for example, d.b.h., basal area) (O'Hara and Latham 1995; Oliver 1981; Oliver and Larson 1990). There is a relatively even distribution of structural stages across whitebark cover types under historical conditions, but a

Table 1—Land area (km²) occupied by the two whitebark pine cover types stratified by PVT and time (historical and current).

Cover types by time period	Potential vegetation types			
	SF Harsh PVT ^a		WBP/AL PVT ^b	
	ICBR	BMW	ICBR	BMW
----- km ² -----				
Current (circa 1990)				
WBP ^c	217	0	9,135	934
WBP/AL ^d	0	0	99	0
Historical (circa 1990)				
WBP	9,327	563	5,793	374
WBP/AL	0	0	2,108	560

^aSF Harsh PVT = spruce fir PVT on harsh environments, usually high elevation, xeric forests.

^bWBP/AL PVT = whitebark pine/alpine larch PVT, usually high elevation cold, xeric forests.

^cWBP = whitebark pine cover type.

^dWBP/AL = whitebark pine/alpine larch cover type.

Table 2—General description of important ecosystem processes across the Bob Marshall Wilderness Complex and entire Interior Columbia River Basin for both SF Harsh and WBP/AL PVTs.

Ecosystem process	Current conditions		Historic conditions	
	ICBR	BMW	ICBR	BMW
Precipitation (mm)	973	1271	NA	NA
Radiation (kW m ⁻²)	317	251	NA	NA
Temperature (°C)	0.8	1.6	NA	NA
Fuel loading (kg m ⁻²)	7.3	6.1	4.1	5.0
Fire regime-frequency ^e	Very infrequent	Infrequent	Infrequent	Infrequent
Fire regime-severity	Stand replacement	Mixed	Mixed	Mixed
Parent material	Calcareous intrusive	Meta-siltstones	Calcareous intrusives	Meta-siltstones

^eVery infrequent = greater than 150-300 years, infrequent = 75-150 years.

^fStand-replacement = all trees killed, mixed patchy = patchy fire killing all trees in some places or only killing a portion of the trees.

Table 3—Current and historic land area (km²) occupied by each structural stage for both whitebark pine cover types (WBP and WBP/SL Cts) across the Interior Columbia River Basin and the Bob Marshall Wilderness Complex.

Structural stage	Current		Historical	
	ICRB	BMWC	CRB	BMWC
Stand initiation	176	0	2,540	233
Stem exclusion	29	0	1,127	117
Stem reinitiation	50	0	1,669	105
Old growth	17	0	2,592	303
Young multistrata	41	0	2,275	303
Old single strata	9,138	934	7,025	482
Totals	9,451	934	17,228	1,497

skewed distribution today with most land area in the old single strata structural stage. This seems true for both the Interior Columbia River Basin and the Bob Marshall Wilderness Complex. The old single strata structural stage is either created from repeated, low severity surface fires, or from high snowfall and cold conditions found in the severe WBP/AL PVT. The even distribution of structural stages under historical conditions probably indicates a mixed or stand-replacement fire regime in the SF Harsh PVT where whitebark pine cover types are in all stages of development (Arno 1986). This seems consistent with the fire regimes data layer.

Related Management Issues—Current management issues are sometimes directly dependent on the health of an

ecosystem. Whitebark pine seeds are an important food for many species of wildlife, especially the endangered grizzly bear. GIS analyses reveal that Bob Marshall Wilderness Complex whitebark pine forests comprise about 38 percent of all whitebark pine forests that are within the current range of the grizzly bear, indicating that restoration of this ecosystem might increase grizzly bear numbers. Another GIS query shows that most Interior Columbia River Basin whitebark pine forests (40 percent) are contained in wilderness areas. This would suggest the maintenance of ecosystem health in wilderness depends on restoration of whitebark pine.

Step 2: Simulate Possible Consequences

Investigation of the possible consequences of management actions is accomplished using simulation models. The models CRBSUM and VDDT were used to simulate changes in whitebark pine land cover under current management policies and under a possible restoration alternative (for example, remediation intervention such as planting rust-resistant whitebark pine and restoring historical fire regimes) for the Interior Columbia River Basin (fig. 2) and Bob Marshall Wilderness Complex (fig. 3). Long-term trends show an increase (about 20 percent) in whitebark pine land cover (km²) with remediation intervention but a rapid decrease in whitebark pine cover under current land management (fig. 2). Spatial simulation of these vegetation dynamics reveal that small isolated sites will lose whitebark pine faster than large, contiguous whitebark pine stands.

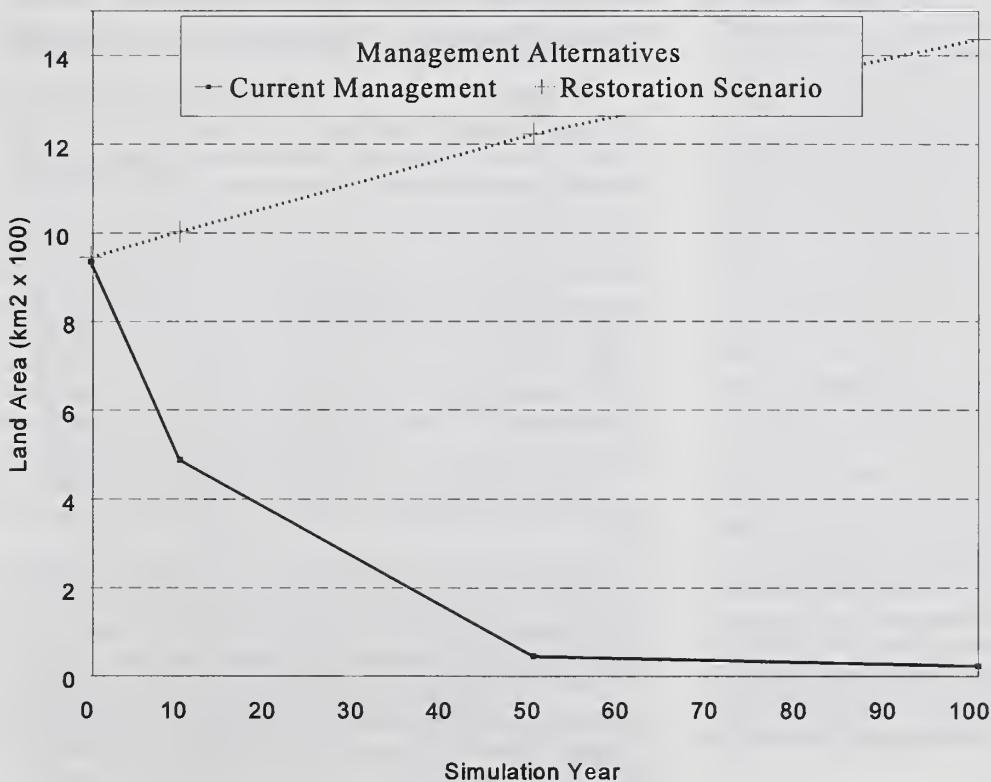


Figure 2—Model predictions of whitebark pine cover type extent (km²) for the Bob Marshall Wilderness Complex under two management scenarios—Current Management and Restoration Scenario.

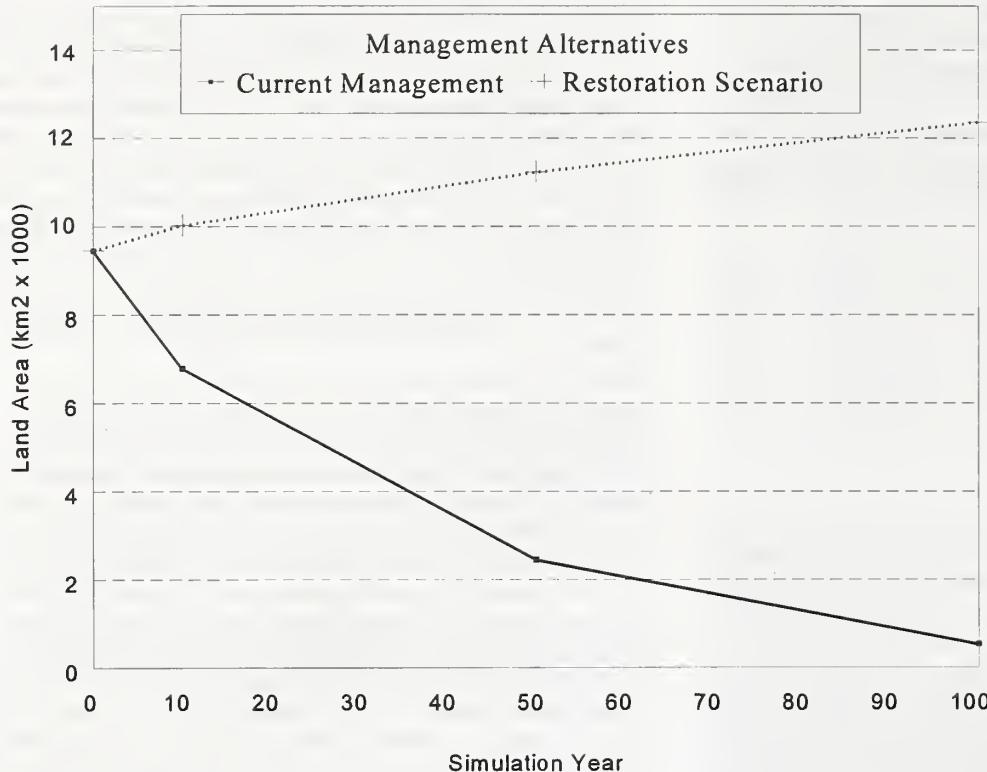


Figure 3—Model predictions of whitebark pine cover type extent (km²) for the entire Interior Columbia River Basin under two management scenarios—Current Management and Restoration Scenario.

Step 3: Prioritize Restoration Areas

Perhaps the most critical step in restoration planning is to identify those areas that need immediate treatment. Coarse-scale data layers and simulation models allow a quantitative analysis of potential restoration sites. Model runs of CRBSUM and VDDT show succession more rapid in the SF Harsh PVT, resulting in a more rapid loss of whitebark pine, but also a faster recovery. GIS queries on the fire regime map indicate that mixed and stand-replacement fire regimes are more common in this PVT. These are the types of fire that are currently excluded on the landscape (Schmidt and McDonald 1990). This suggests restoration projects should target the SF Harsh PVT and that a possible remediation tool should include prescribed fire, especially prescribed natural fires. However, the WBP/AL CT on the WBP/AL PVT is found mostly in the Bob Marshall Wilderness Complex (table 1), so this may be an important condition to maintain or restore.

Advanced GIS analysis of the coarse-scale data layers may also assist in the prioritization of restoration sites. For example, a buffer zone of 15 km in width around whitebark pine cover type pixels will define an effective area of species migration since this is about the distance limit for effective nutcracker seed dispersal (Schmidt and McDonald 1990). Those pixels without overlapping buffers (islands) are areas where nutcracker caches will only have seeds from the local population, and genetic migration from surrounding populations is limited by dispersal distance. These areas can be targeted for planting rust-resistant, nursery-grown seedlings because transportation of natural rust-resistant seed will be limited, and post-fire whitebark regeneration may be

poor when stand-replacement fires burn these isolated areas. Whitebark pine stands in northwestern Montana and northern Idaho might receive high priorities because these whitebark pine forests are in grizzly bear recovery zones and in wilderness areas as assessed from GIS queries.

Step 4: Decide on Restoration Techniques

The objectives of the restoration effort and the current status of ecosystem processes will dictate the techniques used to remediate damaged environments. Objectives of the Bob Marshall Wilderness Complex whitebark pine restoration attempt might be to promote tree establishment and improve cone production. Since the Bob Marshall Wilderness Complex is in a mixed and stand-replacement fire regime, this would indicate the need for an implementation of prescribed mixed and stand-replacement fires in the upper subalpine forests to restore fire's role in ecosystem maintenance. Another objective might be to mitigate blister rust damage in these ecosystems. This could involve the costly planting of rust-resistant seedlings or the less expensive creation of naturally maintained rust-resistant stands of whitebark pine using silvicultural cuttings and prescribed fire.

Ecosystem process conditions will also dictate possible restoration activities. Fire has been excluded from most whitebark pine ecosystems in the Interior Columbia River Basin and the Bob Marshall Wilderness Complex, except for the last two decades when some fires have been allowed to burn under certain prescriptions in the Bob Marshall Wilderness Complex. Consequently, it would seem logical to

incorporate prescribed fire as a tool in restoring ecosystem condition. The introduced blister rust has caused the majority of whitebark pine decline in the northern Rocky Mountains, so restoration plans should include some actions to increase rust-resistance in whitebark pine populations. This might involve the creation of large, burned over areas to encourage nutcracker caching, or the planting of rust-resistant seedlings in critical areas. Subalpine fir replaces whitebark pine in the successional process, indicating that silvicultural cuttings to remove subalpine fir competition would retard or reverse succession and increase whitebark pine abundance and reproductive success.

Conclusions

Coarse-scale information such as the Interior Columbia River Basin spatial data can aid in restoration projects by providing information to plan and design remediation procedures. Coarse-scale GIS layers allow a description of the damaged ecosystem in the context of the entire Interior Columbia River Basin. They also allow a quantification of the processes that affect ecosystem conditions. Simulation models can be used as "gaming" tools to predict the consequences of a restoration procedure on ecosystem health and status.

A general restoration plan for Bob Marshall Wilderness Complex whitebark pine forests has been designed using Interior Columbia River Basin data layers. First, historical fire regimes must be reintroduced to the Bob Marshall Wilderness Complex where mixed and stand-replacement fires burn at infrequent (150-300 years) intervals. Stands of the SF Harsh PVT will be targeted for burning because whitebark pine will be lost first on these types. However, the WBP/AL cover type on the WBP/AL PVT is also targeted for restoration because that cover type occurs mostly in the Bob Marshall Wilderness Complex and rarely elsewhere in the Interior Columbia River Basin. Isolated whitebark pine stands can be targeted for the planting of rust-resistant whitebark pine seedlings.

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Dynamically Incorporating Late-Successional Forest in Sustainable Landscapes

Ann E. Camp
Paul F. Hessburg
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Ecosystems and landscapes change over time as a function of vegetation characteristics and disturbance regimes, including fire. Interactions between disturbance events and forest development (succession) create patterns of vegetation across landscapes. These patterns result from, and change with respect to, species compositions and structures that arise from disturbance events interrupting successional pathways at different points during forest development. Vegetation patterns and disturbance regimes are modified by the effects of topography on the biotic and abiotic processes that drive forest development and disturbance regimes. The propagation and spread of disturbances are heavily influenced by the spatial arrangement of living and dead vegetation across the landscape.

Fire was, and will continue to be, a major disturbance agent in the Inland West. Fire history studies provide evidence that low intensity fires occurred frequently for at least several centuries prior to European-American settlement. This fire regime is characteristic of low and mid elevation sites, especially on south and west-facing aspects, and it perpetuated early-successional, fire-resistant species such as ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*). On mesic sites where fire return intervals were longer, forest development continued into mid- and later-successional conditions before being impacted by disturbance agents that included insects and pathogens as well as higher intensity fires. In much of the Inland West, steep precipitation gradients and rugged, mountainous terrain interacted with fire to create a patchy mosaic of forest stands having different species compositions and age structures. The heterogeneity of fuel loads and host species across the pre-settlement landscape provided a feedback mechanism that inhibited the spread of stand-replacing disturbance events across the landscape.

Not all areas within such a heterogeneous landscape have an equal probability of attaining late-successional compositions and structures, nor of sustaining them over time. Prior to settlement, late-successional stands were embedded in a matrix of fire-resistant, early-successional forest. The occurrence of late-successional forest resulted from combinations of physiography and topography that lengthened fire return intervals, occasionally for periods of one to several centuries. In essence, these late-successional stands were fire "refugia." Fire refugia harbored plant and animal species that

would have been missing if subjected to the characteristic disturbance regime of the surrounding forests.

Since European-American settlement, fire suppression and selective logging of large early-successional trees allowed late-successional tree species to establish and grow in forest understories throughout the Inland West. Individual stands are progressing farther along successional pathways before being interrupted by disturbances. In many areas, dense, multi-layered stands of late-successional true firs (*Abies* sp.) are replacing early-seral forests dominated by pine and larch. Landscape vegetation patterns that inhibited the spread of disturbances are being replaced by more homogeneous patterns in which disturbances such as insect outbreaks and stand-replacing fires can spread rapidly, sometimes with catastrophic effects.

The importance of late-successional forest compositions and structures to critical wildlife habitat is well documented. In a report published in 1993, the Forest Ecosystem Management Assessment Team (FEMAT) recommended setting aside large tracts of land in Washington, Oregon, and northern California to enhance and increase the abundance of old, late-successional forests throughout the Northwest. The practice of setting aside large tracts of land—a static model of custodial management (Botkin 1990)—is the current method for meeting the needs of species requiring late-successional forest habitat. This approach may work in some areas, but in many of the fire-dominated ecosystems and landscapes of the Inland West, large contiguous blocks of late-successional forest are not sustainable. As these forests age, they are at increasingly greater risk to insect and pathogen outbreaks and catastrophic fires that eliminate their function as late-successional habitat.

Fire Refugia in a Late-successional Reserve

In recent research in the Swauk Late-Successional Reserve (LSR) located in the Wenatchee National Forest (fig. 1), we correlated the probabilities of finding late-successional forest predating Euroamerican settlement with site physiography and topography. We found the highest probability for the occurrence of late-successional fire refugia on north-facing aspects at elevations above 1,225 m (4,000 ft) on one of the following topographic settings: at the confluence of two perennial streams, within a valley bottom, on a flat bench, or within a drainage headwall. Within the Swauk LSR, south-facing aspects historically had less than a 2 percent probability of having supported historic late-successional fire refugia.

In: Hardy, Colin C.; Arno, Stephen F., eds. 1996. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

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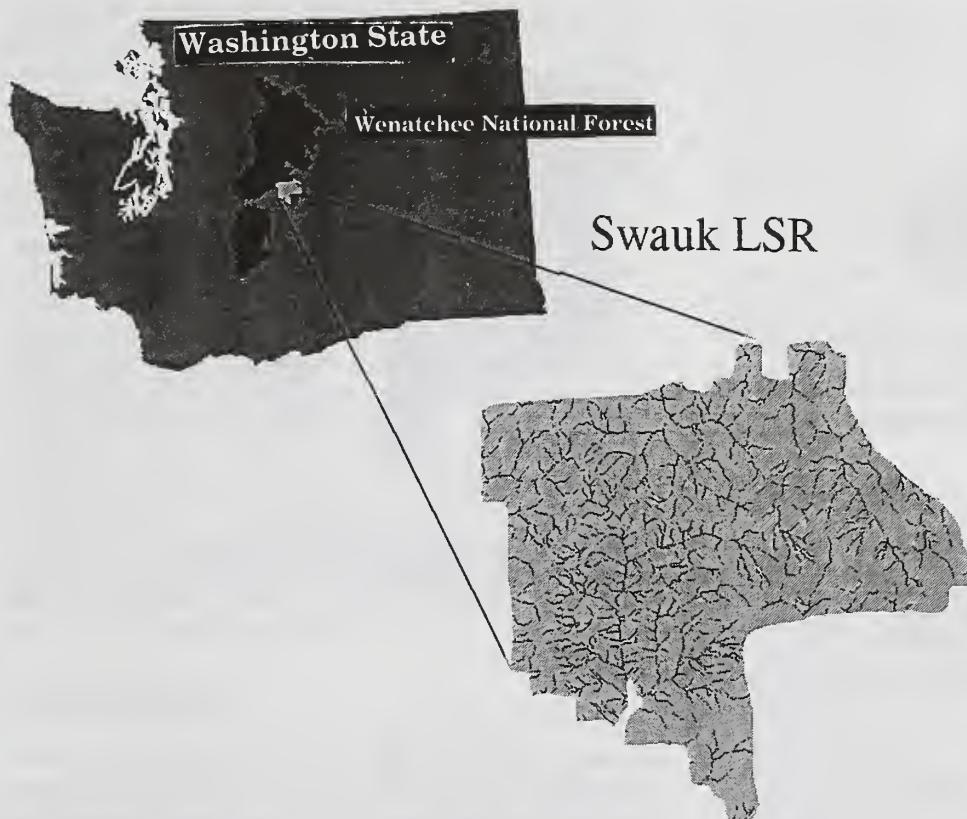


Figure 1—The Swauk Late-Successional Reserve on the Wenatchee National Forest in Washington State.

Predicting the Occurrence of Sustainable Refugia

Applying the results of our research to a digital elevation model of the Swauk LSR, we determined that almost two-thirds of the Reserve had less than a 2 percent probability of supporting late-successional forest (fig. 2). Probabilities of supporting late-successional forest reflect historic fire return intervals. High probability refugia sites had the longest intervals between fires (fig. 3). Immediately prior to Euroamerican settlement, about 12 percent of the Swauk LSR contained stands in mid- or late-successional condition; however, it appears from our research that up to 30 percent of the area within the Reserve has at least a moderate probability for supporting late-successional habitat. The reason that less than half of the potential refugia sites were occupied by late-successional forest stands in the mid to late 1800's was that fires occurred even within refugia, only not as frequently as in the surrounding matrix. Very few of the fire refugia we studied appeared to be persistent landscape patch types. Most existed for several centuries, but then burned—often catastrophically—leaving a legacy of very large snags and logs. Fire refugia within the Swauk LSR were relatively small and spatially unconnected. The largest one in our study was 40 ha. Small, fragmented refugia could not propagate large stand-replacing fires. Stand-replacing fires within refugia probably burned with less intensity and became low- to moderate-intensity fires upon entering the surrounding early-serial landscape.



Figure 2—Nearly two-thirds of the Swauk Late-Successional Reserve (shaded areas) has less than a 2 percent probability of supporting late-successional fire refugia.

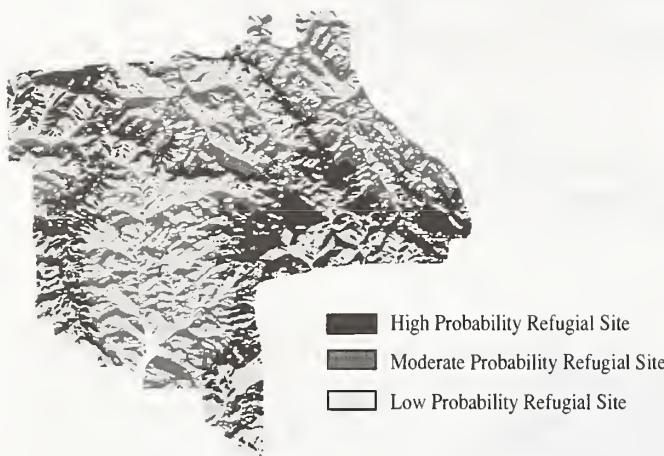


Figure 3—Locations within the Swauk Late-Successional Reserve that historically had high (black), moderate (dark gray), and low (light gray) probabilities of supporting late-successional forests.

Management of Fire Refugia

We used information about historical fire refugia to develop management alternatives within the Swauk LSR that would provide late-successional habitat while minimizing risks of insect outbreaks, diseases, and catastrophic fires. These alternatives reflect a dynamic management model having the flexibility to incorporate varying amounts of late-successional forest with measurable levels of risk to future disturbances.

Old, late-successional forest patches are sited in areas that historically had the highest probability for supporting late-successional forest. These patches and the intervening matrix can be configured in numerous ways, each of which carries a greater or lesser risk of landscape-level disturbances. For example, a low fire-risk alternative would be to keep about one-half of the highest probability refugial sites in old, late-successional forest, with the remainder in younger stands dominated by late-successional species (fig. 4). As they age, younger stands would periodically replace older stands that had deteriorated from pathogen or insect activity. All late-successional patches in this alternative would be small and discontinuous. Areas having low or moderate probabilities for supporting refugia would be maintained in early-seral forests dominated by ponderosa pine and western larch. While this landscape configuration greatly reduces disturbance risks, it may not provide adequate late-successional habitat for some wildlife species.

Another alternative provides greater amounts of older and younger late-successional forest, and greater late-successional connectivity across the landscape (fig. 5). Under this moderate-risk configuration, old late-successional forest is still sited only on historical high-probability refugial sites.

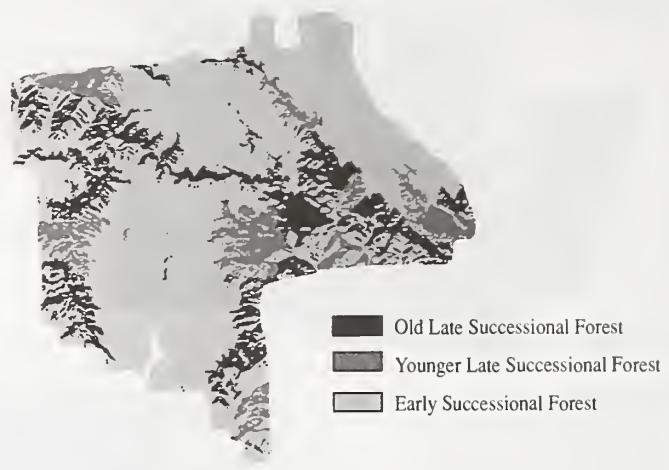


Figure 4—Distribution of successional stages under a low fire-risk alternative.

Greater connectivity is achieved by silviculturally manipulating younger stands in the moderate-probability (moderate risk) areas to develop late-successional composition and structures. These stands would range in age from 50 to about 150 years. As stands approach the upper age limit, they would be evaluated for elevated populations of insects and pathogens. Those most at risk would be harvested, leaving some large trees, both living and dead, to provide late-successional structures within the regenerating stand. Late-successional connectivity would be maintained by younger stands having older forest compositions and structures; this connectivity would shift in both time and space.

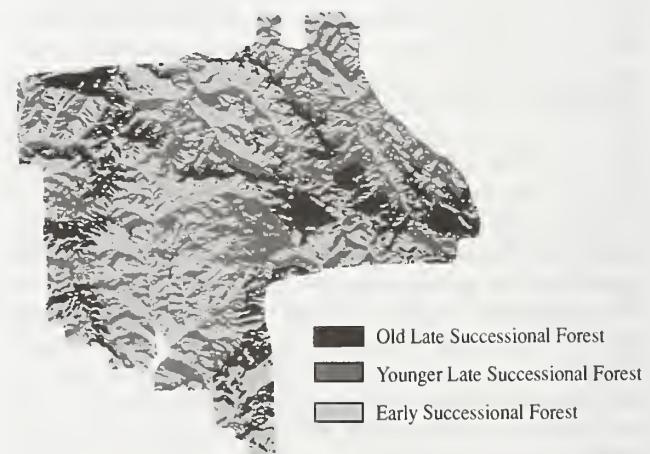


Figure 5—Distribution of successional stages under a moderate fire-risk alternative.

High-risk sites would be maintained in early-serial conditions (as in open park-like stands). In some cases later-successional understories within these early-serial stands might be allowed to develop for several decades before being removed. While this landscape configuration carries a greater risk of fire and other disturbances than the first alternative, it is still much more sustainable than present conditions in the Swauk LSR where aging late-successional forests occur extensively on high-risk sites (fig. 6).

A dynamic approach to incorporating late-successional forest habitat allows a pro-active management response to conditions such as droughts and global warming. Adjustments to the total amount of late-successional habitat and its connectivity across the landscape can be made where risk of habitat loss is greatest. A sustainable landscape is not static, but changes within a particular range of disturbance frequency, intensity, and extent. Managing landscapes using a static model of custodially managed reserves leaves landscapes in the Inland West at great risk to insects, diseases, and catastrophic fires. A dynamic model provides late-successional habitat that can be sustained over time and within changing conditions.

Conclusions

For a Late-Successional Reserve to sustainably provide critical habitat, old, late-successional forest must be sited where the probability of its destruction by fire, insects, or pathogens is low. Since areas of historic fire refugia fall

within existing Reserves and outside Reserve boundaries, we suggest that late-successional habitat be sustainably incorporated into all areas, regardless of their emphasized use. Using younger stands having some old forest composition and structure can augment levels of late-successional forest and provide connectivity. Younger stands can be silviculturally manipulated to produce large trees and multiple canopy layers more rapidly than would occur without active management. These younger stands will necessarily shift in space and time, thus our model of managing for late-successional habitat is a dynamic one. Sites at high risk for fires should be managed primarily for early-successional species such as ponderosa pine and western larch. Disturbance risks change over time, and a dynamic model such as this one can be adjusted more rapidly to meet those changes.

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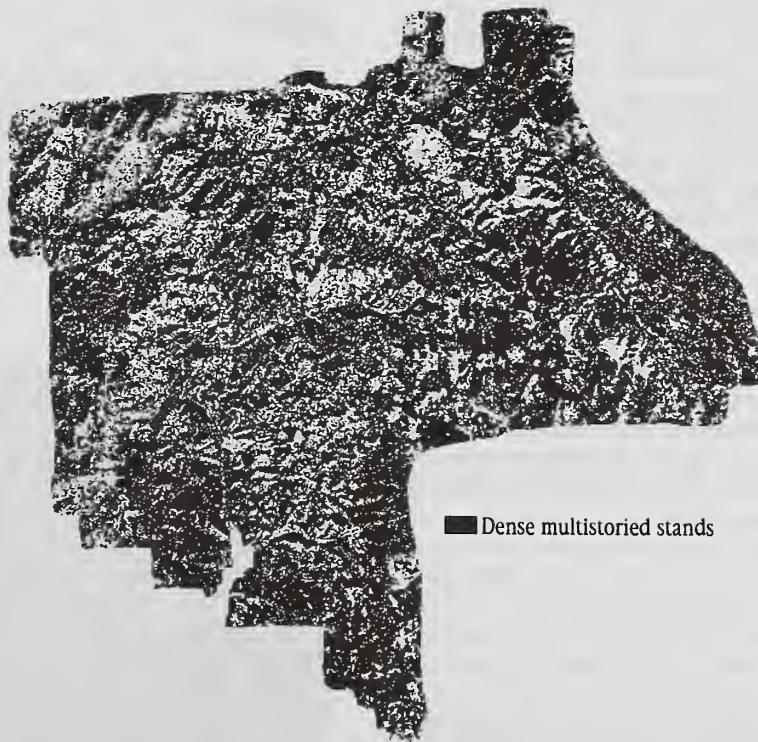


Figure 6—Dense multistoried stands in the Swauk Late-Successional Reserve occur extensively on high-risk sites.

Smoke Considerations for Using Fire in Maintaining Healthy Forest Ecosystems

Roger D. Ottmar
Mark D. Schaaf
Ernesto Alvarado

Fire is the single most important ecological disturbance process throughout the interior Pacific Northwest (Mutch and others 1993; Agee 1994). It is also a natural process that helps maintain a diverse ecological landscape. Fire suppression and timber harvesting have drastically altered this process during the past 50 to 90 years. Natural resource specialists generally agree that the forests of the interior Pacific Northwest are less healthy, less diverse, and more susceptible to larger and more destructive wildfires as a result of this human intervention (Everett 1994). Analysis of current and historical aerial photographs for the East Side Forest Health Assessment (Huff and others 1995) indicates there has been an increase in forest fuels, crown fire potential, and smoke production potential since the 1930's brought on by selective logging and fire suppression activities. In addition, acres burned by wildfires across Washington and Oregon on USDA Forest Service lands have been increasing (fig. 1).

Prescribed fire, often in combination with other management techniques, can be used to restore wildland forests to a more sustainable structure while simultaneously reducing the potential for catastrophic wildfires (fig. 2). Unfortunately, prescribed fire runs contrary to current Federal and state environmental laws because any fire event has the potential to degrade ambient air quality, impair visibility, and expose the public to unhealthy pollutants.

Air regulatory agencies and the public must come to understand the complex tradeoffs between increased prescribed fire, inevitable wildfire, forest health, visibility impairment, and public exposure to smoke before this issue can be resolved. To improve this understanding, land managers and researchers have cooperated in two development activities. The first activity we discuss in this paper is called the Wildfire/Prescribed Fire Tradeoff Model (FETM), a stochastic simulation model to evaluate the tradeoff between prescribed fire and wildfire emissions over time. The second activity we present is an assessment of prescribed fire and wildfire emissions over time for 337 watersheds within the Columbia River Basin.

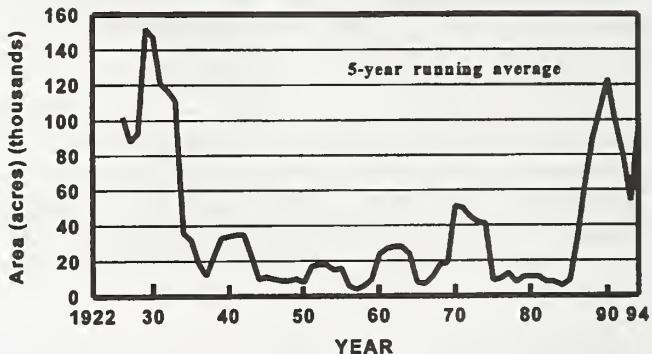


Figure 1—Five-year running average of wildfire acreage burned in Region 6 between 1922 and 1994 (unpublished wildfire data for USDA Forest Service, Pacific Northwest Region).

Wildfire/Prescribed Fire Tradeoff Model

For air regulatory agencies to consider a substantial increase in prescribed fire emissions, it will be necessary to demonstrate that the program would reduce the total emissions from both wildfire and prescribed fire. In 1994, the USDA Forest Service, Pacific Northwest Region brought together a team of managers, scientists, and a private consultant to embark on a model development project to test



Figure 2—Prescribed burn in northeastern Oregon.

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the hypothesis that a reduction in total smoke emissions should occur in northeast Oregon following an expansion of the current prescribed burning program. The objective of the project was to determine the level of prescribed fire treatment that would minimize combined emissions from both prescribed and wild fires. To accomplish this objective, a stochastic simulation model—the Fire Emissions Tradeoff Model (FETM)—was developed to track acreage distribution by utilization, mechanical treatment, prescribed fire, wildfire, and natural succession in 192 fuel types over time (fig. 3). The model was evaluated on the 1.2 million acre Grande Ronde River Basin in northeastern Oregon.

The model was evaluated using the arithmetically averaged results from 30 independent model simulations, each consisting of six levels of prescribed fire treatment (zero through 5 percent of the evaluation area per year, in 1 percent increments) over 100 years of simulation. The preliminary results showed that under the conditions that currently exist in the Grande Ronde River Basin, the total emissions from wildfire and prescribed fire is expected to increase continuously over the next 40 years with increasing levels of prescribed fire treatment. Between 40 and 80 years hence, the total fire emissions are expected to remain constant with increasing levels of prescribed fire treatment. Beyond about 80 years, a slight dip in the total emissions curve is expected to occur, with the minimum point at about the 4 percent level of prescribed fire treatment (fig. 4).

The FETM model also produced a dramatic reduction in the number of wildfire acres burned, and associated wildfire smoke emissions, with increasing levels of prescribed fire treatment. However, the decrease in wildfire emissions was largely offset by the increase in prescribed fire emissions. In the future, a combination of prescribed fire and non-smoke-producing silvicultural methods (such as thinning and whole-tree utilization) will likely be needed to mitigate the current fire hazard and to minimize total smoke emissions in the Grande Ronde River Basin.

Future plans for FETM include (1) adapting the model for use in other river basins of the Western States, (2) improving the crown fire algorithms, and (3) modifying the user interface for land managers.

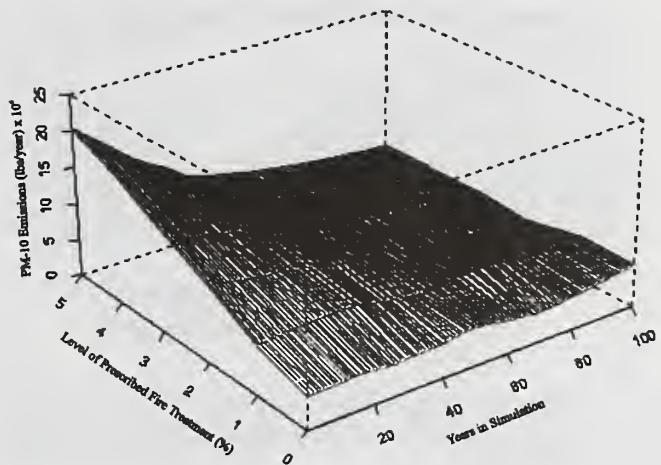


Figure 4—FETM-generated surface plot of combined wildfire and prescribed fire emission PM10 emissions.

Prescribed Fire and Wildfire Emissions Assessment of the Interior Columbia River Basin

The mid-scale assessment of prescribed fire and wildfire smoke emissions within the Interior Columbia River Basin is one portion of the landscape ecological assessment to characterize changes in natural resource conditions of all lands within the Interior Columbia River Basin. This assessment will provide information for USDA Forest Service and USDI Bureau of Land Management decisionmakers who administer lands in this area. The objectives of the smoke emissions portion of this assessment are to (1) describe the variation of smoke production from prescribed fires and wildfires over time; (2) describe current variation in smoke produced by prescribed burning in selected watersheds and Ecological Reporting Units (ERU), and assess the deviation from proposed increases in prescribed burning; and (3) examine tradeoffs in air quality with regards to managed fire, wildfire, and forest health.

Methodology

We modeled the loading (quantity by mass) of dead surface fuels and the smoke emissions from potential wildfires and prescribed fires for each GIS polygon coverage for a historical (1930's to 1960's) and current (1985 to 1993) period of time in 337 selected watersheds within the Interior Columbia River Basin Ecological Reporting Units (fig. 5). Vegetation, stand structural stage, and logging type classifications were delineated from historical and current aerial photograph interpretations by Hessburg and others (1995). We used published information and expert knowledge to assign ground fuel loadings for each GIS polygon coverage. We used the CONSUME (Ottmar and others 1993) and FOFEM (Keane and others 1990) model algorithms to estimate potential fuel consumption under wildfire conditions (large, woody fuel moisture content of 15 percent), fall prescribed fire conditions (large, woody fuel moisture content of 30 percent), and spring prescribed fire conditions

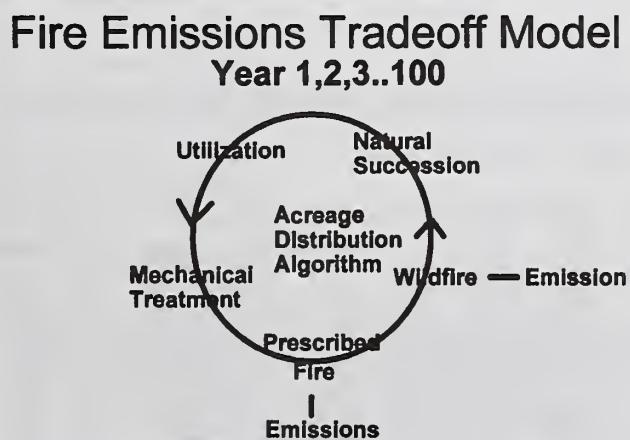


Figure 3—Fire emissions tradeoff model.

Columbia River Basin Ecological Reporting Units

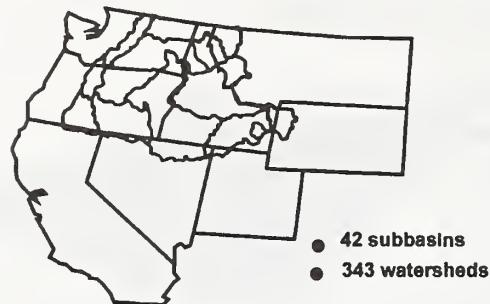


Figure 5—Ecological reporting units for the Interior Columbia River Basin Assessment.

(large, woody fuel moisture content of 40 percent). We used emission factors developed by Ward and Hardy (1995) for the burning of biomass to calculate the potential emissions production. The emission factors correspond to a flaming and smoldering consumption ratio for each fuel condition class and fuel model. Each emission factor was expressed as grams of particulate matter less than 10 micrometers in diameter (PM10) produced per ton of fuel consumed. The PM10 emission factors are inferred values from real measurements collected for (1) all particulate matter and (2) particulate matter less than 2.5 micrometers in diameter (Ward and Hardy 1991). We used PM10 emission factors because most current regulations are based on PM10 standards. Potential PM10 smoke production was estimated, on a per acre basis, by multiplying fuel consumption by an assigned emission factor for PM10.

Fuel Loading Results

Average loading of dead surface fuels for each of the 13 ERUs ranged from 5.3 tons per acre on the shrubland-covered Upper Snake ERU (current) to 25 tons per acre on the forested Lower Clark Fork ERU (current) (table 1). Eight of the 13 ERUs have experienced an increasing trend toward higher fuel loadings over time (fig. 6). The remaining ERUs

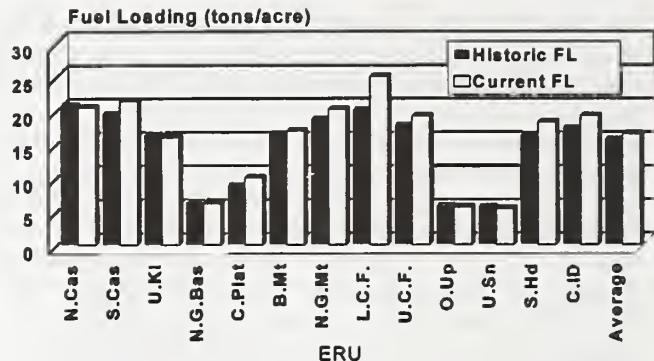


Figure 6—Historical and current fuel loading for Ecological Reporting Units of the Interior Columbia River Basin.

experienced a decreasing trend. The fuel loading differences between the historical and current periods at the ERU levels were very small except for the Lower Clark Fork ERU (with an increase of nearly 5 tons per acre).

Although the fuel loading differences at the ERU level were rather small, many of the sample watersheds within an ERU indicated large differences (fig. 7) (table 2). For example, the Blue Mountain ERU showed an increase of 0.3 tons per acre in fuel loading. The Wallowa watershed #35, however, had a decrease of 6.7 tons per acre in dead surface fuels. This watershed was located in the Eagle Cap Wilderness area, where no harvesting activities had occurred in the past.

Upon reviewing the vegetation types, as delineated through aerial photograph interpretations, a shift in tree species was apparent. Relative amounts of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) forests decreased while whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*) stands increased. Further investigation indicated the area had been burned during several episodes in the past 20 years. This accounted for the shift in vegetation and the decrease in fuel.

The Lower Grande Ronde watershed #55 indicated the opposite trend. It had an increase of 6.2 tons per acre in dead fuels from historical to current. Watershed #55 is located 60

Table 1—Fuel loading and PM10 emissions for dry (wildfires) and wet (spring prescribed fires) for the Ecological Reporting Units of the Interior Columbia River Basin.

ERU		N.G.Ba													Average ¹
		N.Cas	S.Cas	U.KI	s4	C.Plat	B.Mt	N.G.Mt	L.C.F.	U.C.F.	O.Up	U.Sn	S.Hd	C.ID	
Fuel Loading (tons/ac)	Historic	20.94	19.55	16.44	6.47	8.92	16.62	18.77	20.19	17.89	5.87	5.71	16.43	17.73	15.74
	Current	20.39	21.36	15.94	6.06	9.94	16.88	20.15	25.03	19.09	5.57	5.33	18.18	19.11	16.45
	Change	-0.55	+1.81	-0.50	-0.41	+1.02	+0.26	+1.38	+4.84	+1.20	-0.30	-0.38	+1.75	+1.38	+0.71
PM10 Dry (Wildfire) (lb/ac)	Historic	407.71	381.65	308.94	127.62	167.37	314.37	370.80	389.10	345.05	122.09	120.12	320.90	351.18	306.23
	Current	395.15	407.59	286.97	117.13	182.24	320.72	393.97	498.19	369.78	115.30	111.42	360.30	382.33	318.99
	Change	-12.56	+25.94	-21.97	-10.49	+14.87	+6.35	+23.17	+109.09	+24.73	-6.79	-8.70	+39.40	+31.15	+12.75
PM10 Wet (Prescribed fire, spring) (lb/ac)	Historic	120.56	120.74	109.09	60.73	67.31	105.40	106.98	162.49	108.53	60.51	56.07	92.75	100.75	98.59
	Current	138.52	160.26	133.79	54.93	80.29	118.87	139.32	177.69	131.00	56.55	50.45	100.44	107.62	114.17
	Change	+17.96	+39.52	+24.70	-5.80	+12.98	+13.47	+32.34	+15.20	+22.47	-3.96	-5.62	+7.69	+6.87	+15.58

¹Average weighted by the number of watersheds in each ERU.

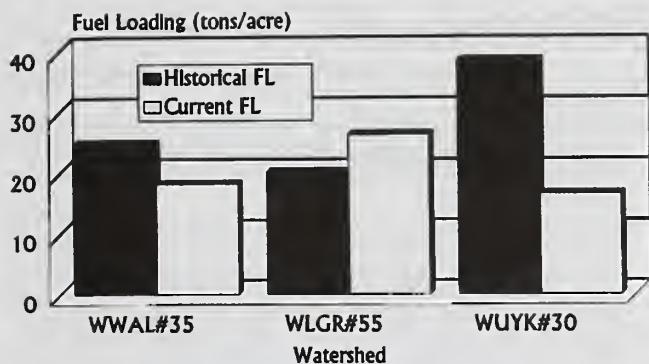


Figure 7—Historical and current dead surface fuel loadings (FL) for selected watersheds.

Table 2—Fuel loading and PM10 emissions for dry (wildfires) and wet (spring prescribed fires) for sample watersheds of the Interior Columbia River Basin.

ERU	WAL#35	LGR#55	UYK#30
Fuel Loading (tons/ac)	Historic 24.89	20.18	38.41
	Current 18.20	26.35	16.54
	Change -6.69	6.17	-21.87
PM10 Dry (Wildfire) (lb/ac)	Historic 501.22	379.63	727.00
	Current 357.84	566.59	310.64
	Change -143.38	186.96	-416.36
PM10 Wet (Prescribed fire, spring) (lb/ac)	Historic 110.89	96.18	188.45
	Current 89.68	118.41	100.12
	Change -21.21	22.23	-88.33

miles north of watershed #35 and is within the Wenaha-Tucannon Wilderness, where no harvesting or large wildfires have occurred during the period. A shift in vegetation was also noted in the photograph interpretations. The watershed changed from a predominantly open ponderosa pine (*Pinus ponderosa*) and young Douglas-fir (*Pseudotsuga menziesii*) stand with dry meadows to older stands, dominated by Douglas-fir and true fir (*Abies spp.*). The current stands had fewer open areas, resulting in an increase in fuels over time.

The Upper Yakima watershed #30 showed a decrease of nearly 22 tons per acre between historic and current dead fuels (fig. 7). A combination of harvest activity and wildfires shifted a large portion of the vegetation type to younger-age stands and decreased fuel loading. Aerial photographic interpretation indicated nearly 50 percent of the 26,000 acre watershed had logging activity or was burned by wildfire since the historic period.

PM10 Emissions Results

Wildfire smoke production ranged from 111.4 pounds per acre on the Upper Snake ERU (current) where the dominant vegetation was shrubland, to 498.2 pounds per acre on the Lower Clark Fork ERU (current) where the dominant vegetation was coniferous forest (fig. 8) (table 1). Potential prescribed fire smoke production ranged from 50.5 pounds per acre on the Upper Snake (current) to 177.7 pounds per ton on the Lower Clark Fork ERU (current).

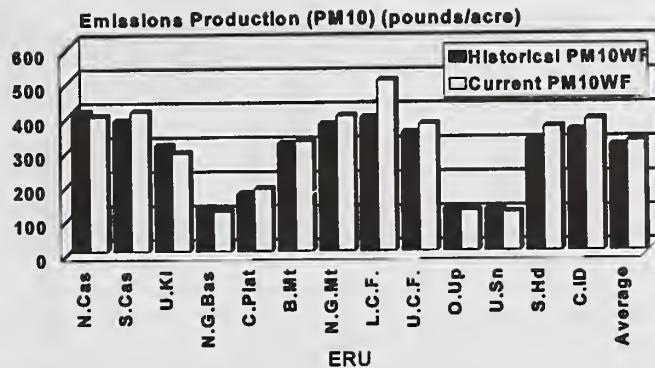


Figure 8—Potential wildfire emission production (PM10) for the Ecological Reporting Units of the Interior Columbia River Basin.

The small differences between the historic and current fuel quantities at the ERU level generated a small difference in potential PM10 smoke production for both wildfires and prescribed fires (fig. 8). The greatest difference between historic and current potential smoke emissions for wildfires was in the Lower Clark Fork ERU, which showed an increase from historic to current of 109.1 pounds per acre. The greatest difference for prescribed fire was in the Southern Cascades ERU, with an increase of 39.5 pounds per acre (table 1).

Areas such as Wallowa watershed #35 and Upper Yakima watershed #30, where harvest activity and/or disturbance occurred, showed a trend toward lower fuel loadings and lower potential emissions production (fig. 9). Areas such as Lower Grande Ronde watershed #55, where fire had been excluded, showed a trend toward higher fuel loadings and higher potential smoke production from wildfires. A wildfire burning in that watershed today would generate 187 more pounds of PM10 per acre burned than if the same fire had occurred during the historical period (fig. 9).

We also noted a large difference between wildfire and prescribed fire smoke production (fig. 10). Potential PM10 from a wildfire was twice the amount as from a prescribed fire of the same size for the current period (at both the ERU and watershed levels).

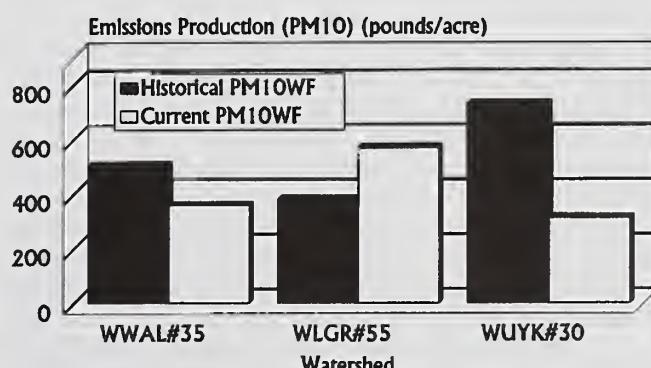


Figure 9—Historical and current potential wildfire emission production for selected watersheds.

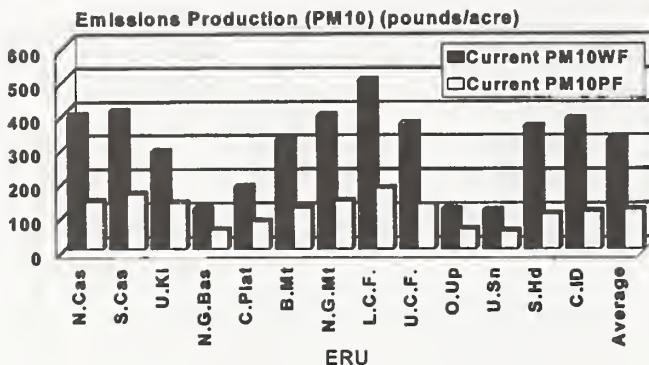


Figure 10—Potential wildfire (PM10WF) and prescribed fire (PM10PF) emissions production (PM10) for the Ecological Reporting Units of the Interior Columbia River Basin.

Conclusions

Air quality regulations have the potential to seriously limit land management actions that use fire for ecological restoration. Air regulatory agencies, land managers, and the public must understand the complex tradeoff issues that the reintroduction of fire poses in terms of forest health, wildfire occurrence, visibility degradation, and human health. The burden of proof is with the land manager to provide estimates of the potential impacts from fire use scenarios and monitor for those effects. The best opportunity to keep fire as a viable tool in ecological restoration involves (1) fostering an atmosphere of cooperation between regulatory agencies and the public and (2) providing a sound impact analysis of management activities.

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Restoration of Fire in National Parks

David J. Parsons
Stephen J. Botti

Over the past century, policies related to the management of fire in U.S. National Parks have evolved from efforts to eliminate all fire to recognition of the importance of restoring and maintaining fire as a natural ecological process. Prior to their formal designation by Congress, most National Parks had experienced thousands of years of periodic fire. Long-term interactions of climate, vegetation, and fire are largely responsible for shaping the ecosystems that most parks were established to protect.

Early European explorers frequently commented on their observations of fire (both lightning and Indian ignited) burning in western forests. John Muir's (1901) detailed observations of a 1875 fire in the sequoia forests of the southern Sierra Nevada provide a particularly vivid account of the patchiness of presettlement fire behavior. Yet, when the first National Parks were established, Yellowstone in 1872, and Sequoia, General Grant, and Yosemite in 1890, the dynamic nature of the park ecosystems was given little attention. The emphasis was on scenery and the protection of objects, for example, geysers, waterfalls, deep canyons, big trees, and charismatic fauna (Graber 1985). Early park management was functionally equivalent to museum curation (Christensen 1995) with emphasis on the protection and enjoyment of the scenery. Realistically, this meant control or elimination of everything considered to detract from the scenery, for example, predators, insects, disease, and of course, fire. The importance of ecosystem processes such as fire were poorly, if at all, understood.

Despite a policy of fire suppression, there was little effective control of fire in the early years of the National Parks (van Wagtendonk 1991). It took creation of the Civilian Conservation Corps in the 1930's and the post World War II surge in availability of aircraft and other technological advances for fire suppression efforts to become fully effective. The increasing effectiveness of these efforts led to the buildup of a complex suppression infrastructure that included virtually unlimited funding for firefighting. Fire suppression became firmly ingrained as a dominant agency philosophy that was enthusiastically enacted with a confidence that belied understanding of its long-term consequences. Yet the stage was being set for later concern over hazardous fuel accumulations, a lack of reproduction of key species, and forest health problems caused by the interaction of overstocked stands, drought, and insects.

A report by Starker Leopold and others (1963) to the Secretary of Interior provided the first widespread recognition of the effects of fire suppression in altering park

ecosystems. In recommending active restoration of presettlement conditions, articulated as a largely static view of "vignettes" of primitive America, the report recognized how the exclusion of fire had changed park ecosystems and the importance of using fire as a tool to restore the "primitive open forest." In 1968 this thinking was incorporated into National Park Service policy by formally recognizing the importance of the presence or absence of fire in determining the characteristics of an area. The new policy permitted the use of prescribed burning and allowed lightning fires to burn to help accomplish approved management objectives (van Wagtendonk 1991).

These policy changes were slowly incorporated into management programs. The first prescribed natural fire program (allowing lightning fires to burn under prescribed conditions) was approved in Sequoia and Kings Canyon National Parks in 1968 (Parsons and van Wagtendonk in press). Experimental prescribed burning programs, with associated research and monitoring, were begun in several parks at about the same time. Despite continued opposition within the agency (Bonnicksen 1989), there was a gradual increase in recognition of the effects of fire exclusion and the importance of restoring fire as a process (Parsons and others 1986). It was recognized that suppression had not eliminated fire; rather it had most often simply changed local fire regimes to include less frequent but more intense fire with results potentially detrimental to management goals.

By 1988, 26 parks had operational prescribed natural fire programs, and many others had active management ignited prescribed fire programs. Although the goals of specific programs may have differed somewhat, National Park Service fire policy emphasized the importance of fire in influencing park ecosystems and the legitimacy of using fire as a tool to achieve resource management objectives (van Wagtendonk 1991). The 1988 fires in the Greater Yellowstone Area (Christensen and others 1989) brought National Park Service fire policies under close scrutiny. The most immediate effect was on the prescribed natural fire program. A moratorium on all prescribed natural fires in 1989 was followed by onerous new implementation guidelines that must be followed before these programs could be reactivated or new programs approved (Botti and Nichols 1995). By 1990 only three parks (Yosemite, Sequoia-Kings Canyon, and Voyageurs) had active prescribed natural fire programs. This number had increased to 20 by the middle of the 1995 fire season. The actual acreage burned in prescribed natural fires since 1990 has yet to approach the average acreage burned prior to the moratorium (an average of 3,708 acres per year has been burned from 1990 to 1994 as opposed to 32,135 acres per year for the 5 years prior to 1988).

Additional concerns regarding the success of the National Park Service's efforts to restore fire to park ecosystems have been raised in relation to the prescribed burning program in

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the sequoia-mixed conifer forests of the Sierra Nevada parks (Parsons 1995). With the goal of restoring fire as a process, burning at similar frequencies and intensities and with similar effects as would have occurred if fire suppression had never been employed, the giant sequoia prescribed fire program at Sequoia and Kings Canyon National Parks has been widely recognized as one of the most progressive fire programs in existence. However, in the 26 years since prescribed burning was initiated in 1968, only 4,515 of the 10,810 acres of giant sequoia forest in the two parks have been burned (by prescribed natural fires, management-ignited fires, prescribed fires, and wildfires). Although the fire history record shows considerable variation, extrapolation from data for the Giant Forest grove indicates an average of 2,600 acres (24 percent of the total acreage) would need to be burned per year to achieve the 4.1 year mean fire interval that occurred between A.D. 500 and 1900 (Swetnam 1993). This compares to a mean of 173 acres per year (1.5 percent) that has actually been burned between 1968 and 1994. Even in the very best of years—743 acres in 1991—the acreage burned under current fire management programs is not sufficient to simulate presettlement fire regimes.

Given the concerns presented over the relative lack of progress being made in restoring fire to anything close to presettlement frequencies, it is only natural to ask what can we expect in the future. Although it is impossible to read the crystal ball, it is apparent that there are a number of obstacles and challenges that must be confronted if the National Park Service is to meet its goal of restoring fire to something approaching its natural role in park ecosystems. Following are some of the most significant challenges that must be addressed:

- Clearly articulate goals and objectives, and define what the role of fire is in achieving them. Managers must articulate what they are managing for. How important are visual, scenery goals as opposed to ecological process goals? What does it mean to manage for “natural” ecosystems? How can our ever improving understanding of the importance of the temporal and spatial variability in ecosystem processes be incorporated into management programs? How do fire-based objectives relate to other ecological and human derived objectives?
- Address the practicality of ever restoring natural fire regimes. Although restoration of natural fire regimes (however natural is defined) remains a valid goal, it is becoming increasingly apparent that will not be possible in many places. Constraints on accomplishing this goal include limited funding, requirements for trained personnel, increasing air quality regulations (and their effects on smoke emissions), and the difficulty in burning large enough areas to replicate presettlement patterns (especially in western forest parks). The Park Service is attempting to address the latter problem by initiating a 6 year experimental program to assess the operational requirements and cost effectiveness of watershed-scale prescribed burning in Sequoia National Park. If it proves impossible to burn the acreage required to approach natural fire regimes it may be

necessary to consider putting available resources into doing a complete job in selected areas, even if it means compromising objectives in other areas. This “zoning” concept has yet to be fully discussed within the agency.

- Recognize the need for continued management intervention. Management boundaries were not selected with natural processes such as fire in mind. Today's boundaries dictate that many fires that in the past would have burned into a park or preserve will be suppressed. Similarly, under current policies suppression actions are often mandated by regional fire conditions. These suppressed fires will need to be replaced with future management ignitions if their effects are not to be lost.
- Availability of qualified personnel during active wildfire seasons. When competition for resources becomes intense, wildfire suppression actions generally take priority over prescribed fire. The lack of resources during the fire season severely restricts the number, size, and intensity of prescribed fires, which, in turn, reduces the ecological significance of the program. To restore natural fire regimes, prescribed fires must burn under natural conditions and with minimum constraints. Partially as a result of this constraint, parks currently fail to carry out about half of all prescribed fire projects funded each year. In an attempt to address this problem, the National Park Service has established four prescribed fire teams that are unavailable for wildfire suppression work, except during extreme emergencies. These are mobile resources that can be dispatched to any park needing additional trained personnel.
- Need for an improved information base upon which to make decisions. As management decisions become increasingly difficult, it is critical that solid information be available on which to make decisions. A strong, credible research program, together with monitoring that provides feedback to managers, is essential to a successful fire restoration program. Understanding of historic and prehistoric fire regimes, interactions between fire, vegetation, and climate, and the ability to assess the consequences of alternative policy or management actions through predictive modelling are especially critical.
- Need for interagency and cross-boundary cooperation. Since political boundaries seldom reflect ecosystem boundaries, the condition or sustainability of a given area is likely to be significantly influenced by what occurs on surrounding lands. Effective coordination, communication, and partnerships between Federal, state, and local agencies and private interests are essential for planning, management, and research.
- Humility and willingness to take risks. It is important that we recognize how much we don't know. Decisions will have to be made on less than perfect knowledge. But they must be made. In many ways our use of prescribed fire is still a long-term experiment, the results of which will take decades to fully assess. Nevertheless, we must be willing to take risks—risks that are based on the best available knowledge.

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The Role of Fire in Research Natural Areas in the Northern Rockies and Pacific Northwest

Sarah E. Greene
Angela Evenden

Forest Service Research Natural Areas are established to preserve examples of all significant natural ecosystems for comparison with those influenced and/or managed by humans, to provide educational and research areas for ecological and environmental studies, and to preserve gene pools for typical and rare and endangered species. The Research Natural Area program in the Northern Rockies and Pacific Northwest regions attempts to protect a wide spectrum of terrestrial and aquatic communities in their "natural" state. At least 79 of the 246 established and proposed Research Natural Areas in these regions represent forest and grassland types that have been adapted to frequent fires over the last several hundred to thousands of years.

Results of Fire Suppression

Due to the increase and intensity of human development and use of the landscape and the suppression of fire over the last 100 years, most of the 79 Research Natural Areas in frequent fire types have shown or are beginning to show one or more of the following: loss of dominant seral species, historically unusual changes in structural patterns, and loss of some early seral community types.

The loss of dominant seral species is obvious in many different types of communities in Research Natural Areas. Exclusion of fire in grassland Research Natural Areas in central and western Montana and in Washington state has led to the encroachment of and increased shading by shrubs and conifers, resulting in a decrease in abundance of species like Idaho fescue (*Festuca idahoensis*), rough fescue (*Festuca scabrella*), bluebunch wheatgrass (*Agropyron spicatum*), prairie Junegrass (*Koeleria cristata*), and needlegrasses (*Stipa* sp.). Oregon white oak (*Quercus garryana*) in the margins of and within the Willamette Valley of Oregon is being supplanted by conifers, especially grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziesii*). Research Natural Areas with historically park-like stands of ponderosa pine (*Pinus ponderosa*) are being invaded by true firs and Douglas-fir, resulting in poor regeneration of pine. Fire suppression in stands of western larch (*Larix occidentalis*) favors Douglas-fir and grand fir regeneration over that of larch.

Fire exclusion and the resultant loss of dominant seral species lead to changes in the structural patterns of Research Natural Areas. In the sagebrush steppe and western juniper zones, Research Natural Areas dominated by grass, herbs, and scattered shrubs are changing to systems dominated by increased shrub cover and tree cover. In many cases those with open, park-like stands of seral tree species are becoming dominated by thickets of saplings and pole-size trees. Unusually large amounts of dead and/or dying regeneration occur in stands of high elevation lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*).

The exclusion of fire in Research Natural Areas is leading to loss of seral successional processes. In the more xeric lodgepole pine types in central Oregon, large fuel build-ups have increased the chances of unusually severe fires that could result in soil damage, potentially disrupting the usual succession following fire. In several eastern Oregon Research Natural Areas, fire exclusion has decreased seral understory species diversity by as much as 50 percent, and the abundance of seral species may have declined dramatically. It is unclear what effects this may have on invertebrate and vertebrate species populations.

Ecological and Operational Challenges to Reintroduction of Fire

Reintroduction of fire through prescribed burning and prescribed natural fires poses ecological and operational challenges. To date, only 5 of the 79 Research Natural Areas needing some level of prescribed fire have been burned.

Often seen as "museum pieces," many Research Natural Areas have poorly articulated management goals. It is not unusual for managers to think that no disturbances (including natural ones) should be allowed.

To reintroduce fire, it often seems necessary to reconstruct the previous fire history; this is time-consuming and expensive. It is questionable whether reintroducing fire from lightning ignitions into small Research Natural Areas makes ecological sense in areas where much larger fires (spreading from other areas) were the norm. It could be that these areas are really just too small to reintroduce lightning fire processes, leading to false conclusions about burning responses. There is also the question of whether the climatic regime today is different from the one under which the stands originally developed.

In some Research Natural Areas, reintroducing fire could adversely provide opportunities for the introduction or increased spread of exotic species. On the other hand, continued exclusion of fire that leads to an unusually severe

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wildfire may encourage exotics even more. We know little about soil invertebrates and their relation to fire regimes. More often than not, management requirements and regulations dictate that prescribed burning occur in seasons other than when fire naturally occurs.

The operational challenges are many. Prescribed burning in Research Natural Areas requires a long-term commitment of personnel and money. It is often difficult to garner the interest and commitment that is required for pre-work and planning, especially when burning is not a high priority. The reintroduction of fire into most Research Natural Areas is generally an open-ended commitment; 5 years is barely a beginning. Money for management of natural fuels has recently been available for burning, but ever-tightening budgets will necessarily make this pool much smaller. On the other hand, the U.S. Department of Agriculture has doubled funding for prescribed burning in its proposed 1996 budget, and Secretary of the Interior Babbitt has urged support for increased funding.

The prescribed burning situation can be complicated when there are private surrounding lands or adjacent lands that are managed with goals that conflict with Research Natural Area goals, for example, timber or other commodity production. Public acceptance and legal restrictions, especially smoke management regulations, complicate matters as well. Difficult access, the need for mop-up, and concern for adjacent lands all make the burning costs relatively high.

The reintroduction of fire into Research Natural Areas should include scientifically defensible monitoring, which is also time consuming and expensive, requiring a long-term commitment on the part of both the scientific community

and the management community. Often only one is willing to participate.

Conclusions

Attempts to exclude fire from wildland ecosystems in the Intermountain and Pacific Northwest Regions have had serious ecological impacts on at least 79 of the established and proposed Research Natural Areas. Numerous ecological and operational challenges face scientists and managers who are committed to restoring the role of fire to these natural areas.

The number of Research Natural Areas needing fire is much greater than the money and personnel available. Those needing prescribed fire should be prioritized into categories that include such things as immediate threats (for example, exotic species), likelihood of being burned by natural causes (for example, high elevation types on ridges), complications from adjacent land management, rarity of the community type protected, and availability of scientists to help set up monitoring. In regard to the last issue, there well may be trade-offs between the ability to monitor and an extreme necessity to burn.

Managers and stewards should look for opportunities to combine prescribed fire in Research Natural Areas with other prescribed fires in adjacent areas, leveraging other fuels management dollars as much as possible. If fire is not somehow reintroduced into Research Natural Areas, they will lose the characteristics for which they were established, either by severe wildfires or by advanced succession.

Restoration of Fire in Inland Forests



The Concept: Restoring Ecological Structure and Process in Ponderosa Pine Forests

Stephen F. Arno

Elimination of the historic pattern of frequent low-intensity fires in ponderosa pine and pine-mixed conifer forests has resulted in major ecological disruptions. Prior to 1900, open stands of large, long-lived, fire-resistant ponderosa pine were typical. These were accompanied in some areas by other fire-dependent species such as western larch. Today, as a result of fire exclusion, most stands have dense thickets of small trees and are experiencing insect and disease epidemics and severe wildfires. These forests cover about 40 million acres in the Western United States and are the focus of concerns about declining forest health (American Forests 1995; Phillips 1995).

The Bitterroot Ecosystem Management Research Project has been testing the effectiveness of different silvicultural and prescribed fire treatments for restoring ponderosa pine forests. (The Bitterroot Ecosystem Management Research Project is an effort of the Intermountain Research Station and the University of Montana's School of Forestry in conjunction with the Bitterroot and Lolo National Forests.) The following four papers report some initial findings. But first I will summarize ecological changes that have occurred and the general concepts being used in restoration treatments.

Restoring more natural and sustainable conditions is complicated by profound changes in stand composition and structure, poor tree vigor, and fuel accumulation that place many stands outside the range of historic variability. A number of studies of historical conditions in ponderosa pine forests have determined that frequent low-intensity fires (average intervals were between 5 and 30 years in most areas) over the last few thousand years were very influential in maintaining open stands dominated by pine and accompanying seral tree and undergrowth species (Arno 1988). Many of these stands were self-perpetuating in uneven-age structures as a result of mortality of small groups of trees and subsequent openings being swept by frequent light fires that favored establishment of the most fire-resistant saplings, pine, and larch (White 1985; Arno and others 1995).

In the late 1800's and early 1900's, dramatic changes occurred in most of these forests. Logging selectively removed most of the large pines, grazing often removed most of the grassy fuels, and fire suppression interrupted the historic fire regime. An abundance of saplings became established and by the mid-1900's developed into dense stands

and thickets of small trees (Weaver 1943, 1967). Numbers of trees and basal areas of tree stems per acre (a rough index of tree biomass) increased markedly. By the late 1900's, this had led to suppressed growth of even the larger trees that contributed to epidemics of insects and diseases covering millions of acres (Mutch and others 1993; American Forests 1992). These trends also occurred in unlogged old growth stands where fire was excluded (Arno and others 1995). In the moist half of this extensive forest type, shade tolerant trees (primarily firs) often became dominant with fire exclusion, producing stands differing greatly in composition as well as structure when compared with historic conditions. These forests occupy semiarid environments and are highly vulnerable to drought when overstocked with trees. They are heavily used by wildlife, for instance as big game winter range, but forage has become sparse as tree cover increased.

Ironically, exclusion of low-intensity fires virtually assures eventual occurrence of large high-intensity fires that kill most trees. Roughly half of the more than 3 million acres that burned in wildfires in 1994 in the Western United States was in these ponderosa pine forests. In an active wildfire year, the expense of attempting to exclude fire from these forests can reach one billion dollars. Paradoxically, these costly attempts at suppression are often unsuccessful. In comparison, costs of restoration treatments are modest. Sometimes the proceeds from harvesting dying trees and small trees will exceed total treatment costs.

Another issue is production of smoke from prescribed burning. Large wildfires produce more smoke than prescribed fires, but land managers are only held responsible for smoke from the latter.

The general concept of restoring natural processes on publicly owned wildland forests is widely accepted. In contrast, acceptable methods for human (manager) interaction with fire-dependent forests are highly debated. The scope of the need for reintroducing fire and fire substitutes on the landscape is staggering. To deal with this, priorities must be set to consider accessible areas where treatments can be done economically and where they can help protect broader areas having high values, such as the suburban/wildland interface.

As a result of ecological and economic evaluations, natural resource managers are highly interested in returning ponderosa pine forests to more historical and sustainable structures. Such strategies involve use of different silvicultural cutting methods along with various adaptations of prescribed burning and fuel removal as described in the following two papers.

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Silvicultural Applications: Restoring Ecological Structure and Process in Ponderosa Pine Forests

Carl E. Fiedler

A primary goal of restoration treatments in ponderosa pine (*Pinus ponderosa*)/fir forests is to create more open stand structures, thereby improving tree vigor and reducing vulnerability to insects, disease, and severe fire. An additional goal in some stands is to manipulate existing species composition and site conditions to favor regeneration of ponderosa pine and other seral species.

Returning fire into dense stands or those with understory (ladder) fuels could fatally damage already stressed overstory trees. For these reasons, restoring ponderosa pine forests to more healthy and sustainable conditions will generally require some kind of silvicultural cutting. A primary advantage of cutting is that it allows for the controlled removal of specific trees in terms of number, size, species, and location. Cutting trees also allows them to be used for forest products, generating income to offset treatment costs.

Ponderosa pine/fir stands that need some kind of restoration treatment represent a continuum of conditions. However, two conditions warrant special attention: (1) overstocked second-growth stands, because of their abundance on the landscape, and (2) overstocked old-growth stands with dense understories, because of their ecological significance.

Before cutting treatments are initiated, general restoration goals need to be established in the form of a target stand or desired future condition. Historical descriptions, old photos, forest inventory records, and field plot data can be pieced together to provide initial targets for restoration. For example, research plot data can provide density targets for thinning (to improve vigor) and for shelterwood and selection cutting (to secure regeneration) in second-growth ponderosa pine stands (Barrett 1979; Fiedler and others 1988).

For old-growth stands in the ponderosa pine type, early written accounts provide qualitative descriptions of structure and composition. For example, Weidman (1921) and Meyer (1934) report that virgin stands in this type were primarily ponderosa pine and many-aged. Tree-ring analyses and reconstructions of age-class structure in old-growth stands provide a quantitative complement to these earlier descriptive accounts (Arno and others 1995).

Restoration Treatment

Together, these sources provide a framework for establishing goals for density, structure, and species composition for overstocked second-growth and declining old-growth

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stands. They also provide a basis for developing restoration treatments to initiate pine regeneration and direct succession toward the appropriate desired future condition.

Overstocked Second-Growth Stands

Density reduction is the primary treatment need in overstocked second-growth stands that commonly range from 120 to more than 200 square feet of basal area per acre. Most of these stands are still primarily ponderosa pine in the overstory, and are young enough to provide a reasonable opportunity for successful restoration. Symptoms of declining vigor in these stands include narrow growth rings in recent years and scattered pockets of bark beetle mortality.

Density targets following treatment in even-age or irregular even-age stands range from 40 to 80 square feet of reserve basal area per acre. This basal area density range is equivalent to about 120 to 240 8-inch trees per acre (tpa), or about 50 to 100 12-inch tpa. Posttreatment basal area targets will typically be on the lower end of this range on drier sites or where regeneration of ponderosa pine is a primary treatment goal, and toward the upper end on better sites or where the goal is thinning rather than regeneration.

The initial cutting leaves the largest and best pines to provide site protection and a well-distributed seed source. While this cutting resembles a shelterwood, it is the first step in a long-term restoration effort to develop uneven-age stand structures, so it is best described as the initial cut in the implementation of the selection system. Future cuttings are planned at 20- to 25-year intervals, with the purpose of reducing stand density and regenerating pine in newly created openings following each entry. The long-term goal is to create and maintain a multi-age ponderosa pine stand, allowing some overstory trees to reach a very large size and become senescent.

A primary goal of the initial cutting in overstocked second-growth is to break up the layer of abutting crowns in the overstory. Harvest cutting that leaves 10- to 30-foot spacing between leave-trees greatly reduces the potential for a wildfire to spread through the upper canopy. If present, sapling and pole ladder fuels can be reduced in density by subsequent thinnings, or they can be removed entirely.

Overstocked Old-Growth Stands

The senescent condition of many trees in old-growth stands makes prospects for restoration uncertain. Furthermore, there are no management guidelines to draw on in terms of density targets for restoration. However, recent old-growth reconstructions of circa 1900 conditions provide a

reasonable basis from which to develop posttreatment targets. Work by Covington and others (1994) in the Southwest, and Arno and others (1995) in the Northwest indicates that pre-1900 stands commonly had basal area densities less than 100 square feet per acre, whereas densities of many existing stands greatly exceed 100 square feet per acre.

The initial harvest entry into old-growth stands typically involves two kinds of cuttings. Selection cutting in the overstory is aimed at reducing stand basal area (to allow regeneration of ponderosa pine), and reducing the amount of Douglas-fir and true firs. Thinning is often needed as well to reduce the density of saplings and poles in the understory. While reserve basal areas of 40 to 60 square feet per acre are recommended for young-growth, uneven-age stands to ensure regeneration of shade-intolerant ponderosa pine (Fiedler and others 1988), somewhat higher reserve densities can be maintained in old-growth stands because site utilization is less per square foot of basal area in large trees than in small trees (Fiedler and Cully 1995). It follows that stands with a considerable proportion of their basal area in large trees will provide a lesser draw on site resources than stands with the same total basal area, but with a large proportion of basal area in small trees.

Experience has shown that leave-tree marking results in a superior reserve stand, because the marker focuses on the highest quality trees at an appropriate spacing. With cut-tree marking, the residual stand is simply comprised of the trees that were not cut (the leftovers). The reserve basal area target—the most important element in the silvicultural prescription—can typically be achieved in the first entry. Scattered small openings are created in the marking process to promote regeneration of ponderosa pine. In contrast to the traditional marking approach aimed at increasing the uniformity of spacing, occasional groups of old-growth trees are left intact (or nearly so) to maintain the inherently clumpy nature of these stands.

Similar cuttings are planned at about 30 year intervals indefinitely into the future. The long-term objective is to maintain the old-growth character, perpetuate ponderosa pine, increase tree vigor, and reduce susceptibility to damaging insects and fire.

Conclusions

While not all restoration needs can be met by silvicultural cutting, some needs are best addressed or can only be addressed by cutting. Furthermore, cutting will generally be the first treatment needed in stands with high density or significant ladder fuels. Silvicultural cuttings followed by compatible prescribed burning treatments comprise an integrated system for initiating the first phase of restoration. Because stands are dynamic, cutting will continue to be needed at regular intervals into the future to reduce overstory density and create openings to favor regeneration of ponderosa pine.

Finally, it is critical that pretreatment conditions and prescribed cutting treatments be documented, and that the target stand or desired future condition be described in terms of density, structure, and species composition. Only then can progress toward the target be measured and interpreted, and future treatments be altered or refined to better meet long-term restoration objectives.

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Prescribed Fire Applications: Restoring Ecological Structure and Process in Ponderosa Pine Forests

Michael G. Harrington

The decision to include the fire process as part of a restoration treatment for a particular forest site is most logically made in conjunction with the decision for a silvicultural treatment. In other words, forest managers do not typically wait to visually or quantitatively evaluate the post harvest site before deciding whether or not to apply fire. Each phase of the restoration effort can effectively relieve only certain aspects of forest problems. So, silviculture and fire are complementary.

Several common silvicultural objectives have been presented. Likewise, it is important to establish specific fire effects objectives so that the proper fire prescription can be developed and applied. Following is a short list and description of some typical fire effects goals that are meant to correct undesirable forest conditions.

The first and most common goal is to reduce the unusually high levels of accumulated organic matter to lessen the potential for severe wildfire (Mutch and others 1993). A conflict may arise because this organic matter may be viewed as an important carbon and inorganic nutrient reserve. However, it is also a forest fuel; and in an environment that has a high probability of wildfire because of climate and fuel type, it should be maintained below some hazard threshold. Applied fire is the most effective and efficient means of achieving and maintaining fuels at low hazard levels.

A second fire effect goal is to reduce the typically high numbers of conifer seedlings and saplings that not only contribute to the wildfire hazard, but also contribute to the forest health problem brought on by severe competition for limited resources (Habeck 1994). Thinning can be useful for removing larger trees, but it is not practical if it is necessary to eliminate thousands of small trees per acre. Again, prescribed fire is quite cost effective and highly efficient in removing most of this undesirable conifer layer. Some trade-offs occur with the loss of sapling thickets that have wildlife value as hiding and thermal cover.

A third goal is the stimulation of vigor in shrubs and herbaceous plants (Wright 1978). These plants were once significant components of the forest understory but have become stressed and decadent because of overmaturity and competition with high numbers of trees. After the competition for soil resources and light has been relieved with tree thinning, these plants typically respond with vigorous sprouting, following top-killing or litter removal by fire.

Interestingly, many plants will not respond to either a burn or reduced competition alone. Both are required. Wildlife forage values usually improve quickly following burning.

A fourth fire effects objective is the partial consumption of the forest floor horizon, resulting in mineral soil seedbeds that are generally required for natural regeneration of seral species (Harrington and Kelsey 1979). Mechanical scarification is sometimes used, but the possibility of soil compaction exists. Another benefit of fire for seedbed alteration is that with combustion, mineralization of organically bound nutrients frequently leads to increases in their availability.

Even though fire can be a valuable tool for restoring unhealthy, hazardous forests, the application of fire is quite challenging. It takes experience and knowledge to develop and carry out a fire application plan that achieves the objectives (Kilgore and Curtis 1987) because treatment goals are generally linked in some way. For example, while achieving the goal of reducing the wildfire hazard, too much forest fuel may be consumed too quickly, leading to severe fire injury to the already stressed forest components. On the other hand, the over-cautious approach occurs when fire is applied under conservative conditions and much effort and expense yield little in the way of accomplishments.

In conclusion, fire is an ecologically sound treatment to consider for restoring altered forests that depended on fire in the past. A strong set of achievable goals must be established by fire effects experts and closely linked to silvicultural goals. Finally, it is important that fire be applied by those experienced in fire behavior and management to reduce the chance of undesirable fire effects.

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Reestablishing Fire-Adapted Communities to Riparian Forests in the Ponderosa Pine Zone

Matthew K. Arno

Ecological research has implicated the practice of fire exclusion as a major contributor to forest health problems in the semiarid ponderosa pine (*Pinus ponderosa*) zone of the Inland West (Mutch and others 1993; Sampson and others 1994). Prior to 1900, frequent, low-intensity fires occurred on upland forests in this forest zone at intervals of 5 to 30 years. With fire exclusion, dense understories and thickets of conifers have developed, producing stands that are highly susceptible to a variety of insect and disease epidemics and severe wildfires. These concerns have led to proposals and a few operational programs to reintroduce fire on a large scale to restore these forests (Kilgore and Curtis 1987; Lolo National Forest 1994; Williams 1995).

Many streamside and riparian areas within the ponderosa pine zone have experienced similar, but even more severe, forest health problems as a result of fire exclusion. However, these problems of advanced succession in riparian areas have received little attention, and the policy of excluding fire is still the unquestioned approach to riparian area management.

Riparian ecosystems are probably the single most productive type of wildlife habitat, benefiting the greatest number of species. For example, in the Great Basin of southeastern Oregon, 299 of the 363 known terrestrial species are either directly dependent on riparian areas or use them more than other habitats (Thomas and others 1979). In western Montana 59 percent of the land bird species use riparian areas for breeding, and 36 percent of those breed only in the riparian habitats (Mosconi and Hutto 1982). One of the reasons riparian areas are so important to wildlife is the diversity of plant species found there.

Riparian vegetation is important to water quality because it acts as a filter, trapping excess sediment, pollution, and nutrients. It also reduces the velocity of flood flows, holds streambanks in place, and shades the stream. The soil in riparian zones acts as a sponge taking up water during high flows and releasing it during low flows.

Prior to 1900, many of the riparian areas associated with the ponderosa pine zone experienced low-intensity fires at a rate of 2-5 per century (McCune 1983; Arno and Petersen 1983). These fires burned in a mosaic pattern leaving much of the vegetation and soil only lightly disturbed, and helped maintain a diversity of plant species far exceeding that found in adjacent upland forests. Riparian communities embedded in the semiarid ponderosa pine zone were historically dominated by relatively open stands of very large

ponderosa pine and western larch (*Larix occidentalis*) that survived the low- to moderate-intensity fires. Understories consisted of a diverse assemblage of tall fruit-bearing shrubs—such as serviceberry (*Amelanchier alnifolia*), hawthorn (*Crataegus douglasii*), chokecherry (*Prunus virginiana*), bittercherry (*P. emarginata*), mountainash (*Sorbus scopulina*), elderberry (*Sambucus spp.*), and mountain maple (*Acer glabrum*)—and succulent forbs and grasses that are scarce in the extensive upland forests (Lackschewitz 1986).

Today, just as on the uplands, many of the disturbance-dependent species are being replaced by dense understories and thickets of shade-tolerant trees (fig. 1). The overstory trees are dead or dying, and there is a buildup of downed fuels along with a dense conifer understory. In many inland riparian areas there is a virtual monoculture of stunted grand fir (*Abies grandis*) without appreciable undergrowth. These conditions allow modern wildfires to sweep through the entire streamside forest in a high intensity burn, leaving little vegetation to protect streambanks and water quality. Storms can readily degrade stream quality after high-intensity wildfires, which are now common in these ponderosa pine zone riparian areas (White 1995).

I am involved in a cooperative study (University of Montana and Intermountain Research Station) that will test restoration treatments on two small streams in the Lolo and Bitterroot National Forests of western Montana. The management goal is to create conditions that will allow a return of seral vegetation and to reduce the hazards of severe wildfire and insect or disease epidemics. The project will demonstrate two feasible methods for removing most of the dense conifer understory.

Three treatments will be compared at each of the two riparian study sites: mechanical thinning alone, mechanical thinning followed by understory burning, and an untreated control. In the two thinning treatments, most of the small, shade-tolerant understory trees that make up the dense thickets will be cut and removed to reduce competition and open up the site to sunlight and precipitation. In addition, many of the shade-tolerant overstory trees will be removed while the seral ponderosa pine and western larch will be left. To minimize soil impacts, all tree removal will be done with a farm tractor equipped with a harvesting winch over frozen, snow-covered ground. In the burn treatment, a fuel bed of grand fir saplings will be left to allow a high level of control over the prescribed burn. The purpose of the burn is to stimulate herbaceous and shrubby vegetation and to create mineral soil microsites suitable for seedbeds. A systematic survey of overstory and understory trees and understory vegetation, as well as the physical and chemical characteristics of the stream, will be made before treatments and for several years after treatments.

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Figure 1—Fire exclusion in riparian areas has created dense understories and thickets of shade-tolerant species, such as grand fir.

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Restoring Recreational and Residential Forests

Joe Scott

Several decades of fire suppression following logging around the turn-of-the-century has produced dense, even-age stands of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). They contrast with the original forests where frequent, low-intensity fires gave rise to open, parklike, and often uneven-age stands of ponderosa pine. Forests in current conditions are prone to insect infestations, disease outbreaks, and severe wildfires. As residential development and recreational use of this forest type continues to increase, the need for low-impact treatments for mitigating the wildfire, insect, and disease hazards likewise increases. Some forest managers have developed "ecosystem management" treatments such as thinning coupled with prescribed burning to address these concerns. However, special considerations must be made in treating high-value forest land like recreation areas and private home sites. This paper emphasizes silvicultural and harvesting concerns with some additional comments on the use of prescribed burning.

Residential and recreational forests are valuable largely because of their aesthetic appeal, so any proposed treatment must consider the preservation or improvement of aesthetic quality. Forest managers have been concerned with the visual quality of forest treatments for quite some time now. However, their concern has generally concentrated on distant views, like those of a mountainside from a town or highway. By contrast, visual quality concerns in residential and recreational forests occur at a finer scale—within a stand of trees, along a trail, in a picnic area, or at a rural home site.

Treatment Design

In designing a restoration treatment for residential or recreational forests, the forester must consider the impact of both the silviculture and the harvest method on aesthetic quality.

Silvicultural Considerations

Silviculture dictates which trees are to be harvested and which are to be retained. A final harvest that removes most of the trees from a site is obviously not desirable from a visual quality standpoint. More appropriate silvicultural treatments are commercial thinning and single-tree selection (STS), also called uneven-age management. Uneven-

age management aims to perpetuate trees of nearly all ages in the stand. Under the classical STS system, at any given point in time the forester tries to maintain more trees in each progressively smaller size class (younger age class). The result is a pleasing forest of both large and small trees, open-grown enough to mitigate hazards resulting from wildfire and insect and disease epidemics.

The other appropriate silvicultural treatment is a commercial thinning. Foresters recognize several broad types of thinning, notably a high thinning and a low thinning. In a low thinning the largest dominant and codominant trees are favored for retention while the smaller, weaker trees are harvested. A high thinning is quite similar except that some of the dominants are harvested and more codominants are retained. This is done because the dominant trees are often less growth-efficient than codominant trees due to the larger amount of tissue they must respire, but also increases the economic viability of the treatment. In general, a low thinning will produce a more visually pleasing stand but a high thinning will increase residual stand growth more. Provided that limbs and tops of harvested trees (slash) and other fuels are treated, thinning will significantly reduce fire, insect, and disease hazards. Given the visually-sensitive nature of residential and recreational forests, a low thinning is usually a better choice.

A forest stand cannot be restored to more desirable conditions by a logging treatment in which only the most economically valuable trees are removed. Such practices generally worsen an unhealthy condition and create an unattractive forest.

Harvest Method

The second factor that must be considered when undertaking a restoration treatment in a residential or recreational setting is the method of harvesting the desired trees. Small, independent loggers working on private and government land often use a rubber-tired skidder or a crawler tractor (bulldozer) for dragging logs to a landing, where they can be loaded onto a truck. The trees are cut with a chainsaw but the limbs and tops are left attached and are skidded to the landing with the logs, where a chainsaw is used to remove the limbs and top. This "whole-tree" skidding method is cost effective because slash can be disposed of at the central landing. Unfortunately, the limbs and treetops contain nutrients that are potentially useful to the remaining forest, so it is better for long-term forest health to leave most of the limbs in the woods. As the limbs decompose or are burned, the nutrients are released into the soil. Another drawback of "whole-tree" skidding is the large landing area required to process the trees and make a pile of limbs and tops. Moreover, the residual trees are often scarred in the process of skidding whole trees, inviting disease.

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Some larger logging contractors use a more automated approach for harvesting trees. The feller-buncher can grab hold of a tree, saw it off, and place it on the ground, making a stack of whole trees oriented with the butt facing the landing. A skidder with a grapple (claws) instead of a winch grabs the whole stack of trees and travels to the landing. At the landing a mechanical delimber removes the limbs and cuts the tree into logs, leaving a pile of limbs for disposal by burning. This fully mechanized harvesting system is quite productive, so logging costs can be kept low. However, the machinery is expensive to move from one job to another, so it is rarely used on the small private properties common in residential areas. Moreover, the machines are large and difficult to maneuver without scarring the residual trees in a stand that is being lightly thinned.

The next generation in harvesting equipment is a feller-processor that makes decks of logs already cut-to-length. An off-road machine called a forwarder carries the logs to the landing without dragging. This system leaves slash on the site to decompose or be burned, but is very expensive and is seldom used on small properties.

Fortunately for private landowners and recreational area managers, there are a wide variety of relatively inexpensive, low-impact harvest methods available. One is perhaps the oldest logging method known—horse logging. Trees are felled with a chainsaw, delimbed and cut into logs right where they fall. Horses are used solo or in tandem to drag the logs to the landing. Limbs are piled by hand and burned, or scattered and left to decay. Horses can be used on any size property and are generally limited to skidding logs downhill or on flat terrain.

Farm tractors modified for use in the woods can be used in restoration treatments where visual concern is high. The harvest method is similar to horse logging, but the tractor uses a three-point hitch-mounted winch (powered by the tractor's power takeoff shaft) to pull logs to the tractor, working effectively even up or down short pitches of very steep slopes. When a full load has been winched to the tractor, the logs are raised (using the tractor's three-point hitch) and skidded to the landing. The winch has a blade that stabilizes the tractor and can be used to organize logs at the landing. Experienced operators can use four-wheel drive tractors with harvesting winches in some areas having moderately steep terrain.

Other methods include the use of all-terrain vehicles (ATV) to skid small logs. A trailer for posts and poles or a skid pan or sulky for logs can be towed behind the ATV. Unlike the farm tractor, an ATV cannot move logs uphill. Forest engineers in Europe have developed other small tracked and wheeled machines that can be used in restoration treatments where mainly small trees are to be harvested.

On steep slopes (greater than 25 percent), plastic chutes (PVC pipe cut in half longitudinally) can be fastened end-to-end to slide small material like firewood and posts to a road or other access point. Wood up to 8 inches in diameter can be "chuted" if the PVC pipe is 10 inches in diameter. This system has been used successfully on slopes over 500 feet long. The kinetic energy on the moving firewood piece can be used to split the wood by mounting a heavy splitting wedge at the bottom of the chute.

Prescribed Burning

Appropriate use or non-use of fire is usually a sensitive consideration in undertaking restoration of a residential or recreational forest. The ponderosa pine type produces large quantities of highly flammable fine fuels (pine needles) each year, and this forest can burn under dry conditions from early spring through autumn. Prescribed burning, after high initial fuel loadings have been reduced by other means, has several advantages from an ecological viewpoint (Arno and Harrington, this proceedings). Prescribed fire is often used to help maintain ponderosa pine forests in public recreation areas, but such burning is uncommon in residential areas because of the higher values at risk and a dislike of the initial visual effects of an underburn. Applying an underburn in a tract of forest near a home clearly requires professional planning, equipment, and execution, but that may be available through insured prescribed fire consultants perhaps aided by cooperating volunteer fire districts.

Conclusions

The forester has many considerations to make when designing a forest restoration treatment in a recreational or residential setting. Fortunately, there are existing silvicultural tools and unique low-impact harvest methods available for restoring forests in an aesthetically sensitive manner.

Determination of Fire-Initiated Landscape Patterns: Restoring Fire Mosaics on the Landscape

Michael Hartwell
Paul Alaback

One of the key limitations in implementing ecosystem management is a lack of accurate information on how forest landscapes have developed over time, reflecting both pre-Euroamerican landscapes and those resulting from more recent disturbance regimes. Landscape patterns are of great importance to the maintenance of biodiversity in general, and particularly in relation to wildlife habitat (Noss and Cooperrider 1994). The study of historical landscape patterns and forest structures can give land managers insight into understanding large-scale temporal and spatial stand dynamics. Historical stand structures can serve as models of naturally functioning, sustainable landscapes. Additionally, comparison of the historical structures with the present can give us insights into the relations of disturbance and environment to stand development. Such understanding is essential to long-term resource planning. There are many approaches available for assessing landscape pattern and stand structure, each with its own insight and limitations. This synopsis discusses an approach of interpreting landscape patterns and their relation to disturbance history in a specific case study.

There are three fundamental approaches to determining historical landscape patterns: (1) the study of historical records or accounts, (2) remote sensing, and (3) ground-based surveys. Before attempting to describe historical landscapes, a knowledge of past anthropogenic activities and other disturbance events is essential, as disturbance is the primary factor in determining forest stand structures. A study into the anthropogenic activity might yield dates or information on forest burning by Native Americans, dates of Euroamerican settlement, and related uses of forests. Historical accounts and vegetation descriptions might be available, but such information is usually quite fragmented and subjective. For example, early surveys might only describe areas that contain large merchantable timber or areas near roads or trails. If one were to rely on this information by itself he might conclude that these forest types covered the entire landscape!

A comparison of patterns through remote sensing can characterize some aspects of broad-scale landscape changes. Aerial photos are indispensable for interpreting general patterns. However, they are limited by an inability to accurately portray specific disturbance agents and their historical

role. Selective logging activities have taken place in the Interior West since the mid-nineteenth century, thus the chance of finding photos that predate Euroamerican activities is rare. Additionally, the introduction of exotic pathogens has affected conifer species composition in the Northern Rocky Mountains (Keane and Arno 1993; O'Laughlin and others 1993). Forest structure and understory patterns from photos and satellite imagery are also difficult to discern. Through remote sensing we run the risk of falsely attributing the cumulative effects of light, low mortality disturbance events to the wrong agents, or of missing fundamental changes in forest structure and function.

The only way to accurately describe historical and current species compositions, forest structures, and disturbance events is through a ground-based study. Using age class analysis of live and dead trees and fire scars, we can describe both historic and contemporary stand structure of overstory trees and identify the major disturbance agents contributing to modern stand structures.

Determination of Landscape Patterns on the Bitterroot Front, Montana

We are currently examining historic and present landscape patterns on the Bitterroot National Forest south of Missoula, Montana. Stands in this forest have experienced both selective and clearcut logging, frequent fires, and insect or pathogen epidemics. Forest records that describe timber sales are not well documented prior to 1950. If available, such records could provide dates of logging entries and could aid in reconstructing age class structures. We are determining approximate logging dates through the interpretation of radial growth release on surviving trees, ages of post-logging stands, and evidence of harvesting technology (for example, stumps created by axe, cross-cut, or chain saw).

We are using a systematic grid of plots over the landscape to describe circa 1900 and present tree species compositions and age-class structures (Arno and others 1993). We used this approach to cover extensive areas in a broad range of forest types between 4,500 and 7,500 feet (mean sea level) on the primary Bitterroot Front, an east-facing escarpment (fig. 1). This elevation range encompasses dry ponderosa pine (*Pinus ponderosa*) in the lower elevations to subalpine fir/whitebark pine (*Abies lasiocarpa/Pinus albicaulis*) forests. We located our study areas within the forested zones of three mountain faces (fig. 2).

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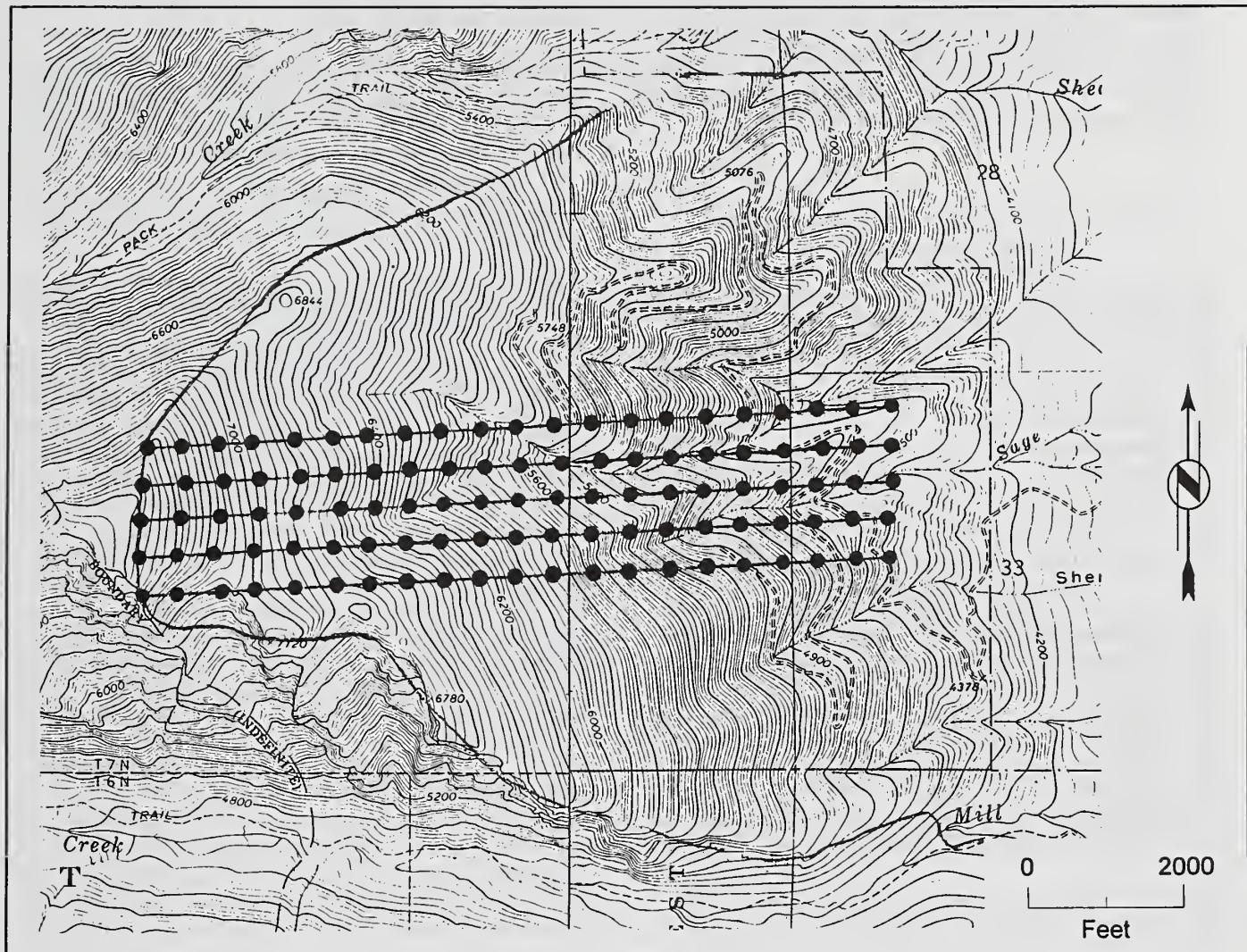


Figure 1—Plot locations in one of the three study sites on the Bitterroot Front.

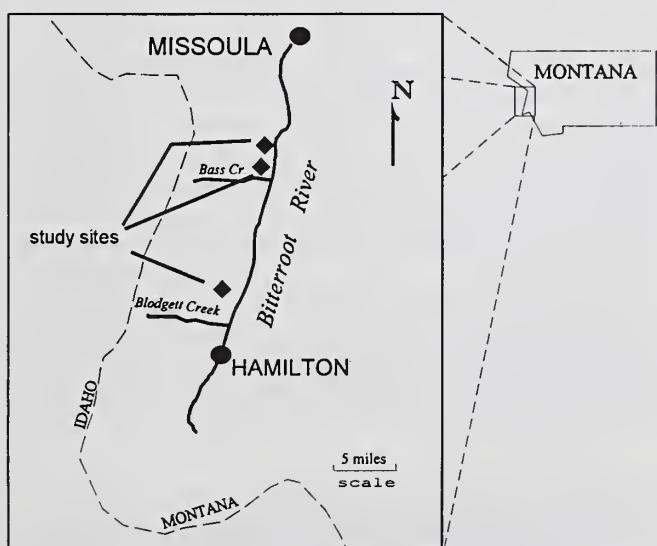


Figure 2—Map of southwestern Montana showing approximate locations of the three study sites.

Our key objectives are to describe: (1) circa 1900 and 1995 species compositions and age-class structures, (2) the relation of stand development to environment (microclimate, soils), and (3) the relation of stand development to disturbance. We recorded tree species by 2 inch diameter classes and identified cohorts of equivalent ages through increment boring near the ground line. Disturbance agents such as fire have been identified at each plot and their severity classified as nonlethal, mixed-mortality or stand replacement. Habitat types (Pfister and others 1977), aspect, slope, and elevation have been recorded at each point.

Application

Our inventory and assessment will provide a detailed picture of landscape processes reflected by shifts in species dominance and age-class structure as a result of disturbance (tables 1 and 2). This will be achieved through coordinated use of historical records, aerial photographs, and the field surveys. Such information will serve as indices to describe

landscape changes in the last hundred years and provide baseline information for broadscale restoration efforts. Results from our studies will build a foundation for the implementation of ecosystem management by providing a quantitative assessment of landscape change.

Table 1—Stand composition of a lodgepole pine forest study area in 1900 and 1991, based on species basal area (Arno and others 1993).

Stand composition	1900	1991
-Percent composition--		
Lodgepole pine	77	57
Subalpine fir	9	17
Whitebark pine	14	0
Mixed species	0	26

Table 2—Percentage of the areas with a given lodgepole pine class (Arno and others 1993).

Structural age class	1900	1991
-Percent composition--		
Seedlings	43	14
Saplings	29	0
Poles	14	43
Mature	40	49
Overmature	14	40
Lodgepole pine absent	0	6

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Restoring Historic Landscape Patterns Through Management: Restoring Fire Mosaics on the Landscape

Cathy Stewart

Seral, fire dependent lodgepole pine (*Pinus contorta* Dougl.) communities are an important component of upper elevation forests throughout the Northern Rockies, where they cover 4 million acres, or about 17 percent of the land base. On the Bitterroot National Forest, lodgepole pine occurs mostly between 5,500 and 7,500 feet.

Two factors strongly influence the fire regime in the lodgepole pine types: cone serotiny and mountain pine beetle epidemics. Serotinous cones have scales that are sealed with resin. The seeds are stored in these cones for many years until they are exposed to heat that melts the resin and allows the scales to open. This allows the tree to disperse the maximum amount of seeds when the conditions are optimum for germination—namely, in the ashes immediately after a forest fire. Cone serotiny is a genetically controlled trait. It is estimated that 70 percent of the lodgepole pine type on the Bitterroot National Forest has predominantly serotinous cones.

Mountain pine beetle (*Dendroctonus ponderosae* Hopk.) plays another integral part in the ecology of lodgepole pine. The adult beetles produce galleries under the bark of the tree and lay eggs. When the eggs hatch, the larvae carve horizontal galleries which girdle the tree and can kill it. Population outbreaks occur on roughly a 20 year cycle (Amman 1978). There were extensive outbreaks of mountain pine beetle populations in the 1970's and 1980's. In Montana, over 800,000 acres of lodgepole pine were infested in 1979 alone (Bennett and others 1979). These outbreaks created heavy fuel loads that, along with drought, helped produce the severe fires of 1988 in Yellowstone National Park.

In the Greater Yellowstone Area, 1.4 million acres burned in 1988. Of these, 61 percent were fires that burned in the forest canopy and 34 percent burned on the ground surface only (Greater Yellowstone Post-Fire Resource Area Survey Team 1988). Additionally, many unburned patches helped create a fire mosaic on the landscape. There has been continuous professional discussion that the intensity of the 1988 fires was within the historical range of fire behavior, but that the scale may have been enlarged due to many years of fire exclusion.

The characteristics used to analyze the historical range of fire activity include fire intensity, frequency, and size (or scale) of fire events. Intensity is characterized by four levels: (1) crown consuming fire; (2) severe surface fire; (3) mixed

severity fire (some trees survive); and (4) low intensity surface fire. Stand replacing fires (levels 1 and 2) kill the majority of trees in their path with occasional patches of live trees surviving. Some larger trees, and especially the fire resistant species, survive in mixed severity fires. Most overstory trees survive low intensity surface fires. The fire intensity in the lodgepole pine type on the Bitterroot National Forest is variable with many sections of stand replacing fire (1 and 2) on steeper slopes bordered by areas of lower intensity fire (3 and 4) on gentler topography. Single or multiple fire scars occur on lodgepole pine in some stands indicating the lower intensity fires.

Fire frequency is indicated by the average interval between fires. Frequent fires in some forest types can maintain reduced fuel levels, resulting in low intensity impacts. Infrequent fires (intervals >50 years) are characterized by higher fuel levels and intensity leading to higher mortality. The four intensity levels can create a pattern of variable intensities over time and across the landscape. Average fire intervals on the Bitterroot National Forest have been measured as being between 32 and 112 years in different lodgepole pine study areas (Arno and Petersen 1983; Brown and others 1994).

All factors of historic fire regimes, including the size of fire events, have been altered due to fire exclusion policies that were instituted early in this century (Brown and others 1994). Surface and ladder (understory trees) fuels have increased. Extensive areas of older forests have developed over time without fire events to break them into a finer mosaic pattern (Arno and others 1993). Fires that have occurred in the region have been observed to have higher intensities due to the increased fuels (Barrett and others 1991; Brown and others 1994).

To characterize the effects of fire on landscape mosaics on the Bitterroot National Forest, an intensive study of historic photos will be done to determine the historic intensity, frequency, and size of fires. Aerial photos from 1937 will be interpreted for stand structure and disturbance mosaics. Patches of similar tree species (forest composition), size classes, and densities (stand structure) will be delineated. The delineations will then be laid over the systematic grid of field plots taken by Mike Hartwell (Hartwell, this proceedings). Field plot information includes tree measurements, stand history, and fire history. The field plots will be matched with air photo patches to determine the fire intervals and intensity of pre-1900 disturbance events within the patches. Measurement of the actual delineations on photos will determine size of individual fire events. The integration of fire intensity, frequency, and patch size information will help characterize and quantify the pattern of mosaics across the landscape of lodgepole pine community types.

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A land management goal is to develop treatments that restore the stand structure, composition, and patterns of the presettlement disturbance regime. Fire frequency information will help us plan the interval of future management activities. This information will be used to update the Bitterroot National Forest's Plan, which is revised each decade. Specific information relating to disturbance size and intensity will aid in the creation of treatment prescriptions. Size of treatment units could be planned to reflect the range of historic events if that is acceptable relative to modern goals for these publicly owned lands. The fire intensity information can help determine the number and species of residual trees that should be left on the site when trying to simulate historic fires.

Fire cannot immediately be returned to all sites as they currently exist and still meet other management objectives. Ladder and surface fuels have increased beyond historic levels and may hamper the direct application of prescribed fire. Pretreatment to remove some trees will be required to reduce fuels to a manageable level before prescribed burning can occur. Understory ladder fuels may also require slashing, piling, and burning before prescribed ignition. Once fuels are reduced, fire can be applied on a larger scale but perhaps not at the historic landscape scale.

Demonstration treatments that are developed on the Bitterroot National Forest will be applied on the Tenderfoot Creek Experimental Forest in central Montana in collaboration with Ward McCaughey, Intermountain Research Station, Bozeman, Montana. The array of treatments will include use of commercial harvest methods with low, medium, and high levels of tree removal. Harvests will be applied with

and without prescribed fire. Controls will also be established for comparison. These treatments will provide detailed monitoring and comparison that will provide valuable information for future management.

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Whitebark Pine Ecosystem Restoration in Western Montana

Robert E. Keane
Stephen F. Arno

Background

Whitebark pine (*Pinus albicaulis*) is a major tree species of upper subalpine forests of the northern Rocky Mountains (Schmidt and McDonald 1990). It is an important nutritional and structural component of wildlife habitat (Arno and Hoff 1990; Schmidt and McDonald 1990). Its large, nutlike seeds are a major food source for many birds and mammals (about 105 species) including squirrels, black and grizzly bears, and Clark's nutcrackers (Hutchins and Lanier 1982). The species protects watersheds by stabilizing soil and rock on the harshest sites and by catching and securing snowpack. Historically, whitebark pine was a major species on 10 to 15 percent of the forest landscape in western Montana and central Idaho (Arno 1986); thus, its perpetuation is of concern for maintaining natural biodiversity and landscape structure.

A rapid decline in whitebark pine has occurred during the last 60 years as a result of three interrelated factors: epidemics of mountain pine beetle (*Dendroctonus ponderosae*); the introduced disease white pine blister rust (*Cronartium ribicola*); and successional replacement by shade-tolerant conifers, specifically subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). The effects of these factors have been exacerbated by fire exclusion policies of the last 60 to 80 years (Kendall and Arno 1990; Keane and Arno 1993).

Whitebark pine benefits from wildland fire because it is more capable of surviving and regenerating after fire than its associated shade-tolerant trees (Arno and Hoff 1990). Whitebark pine is able to survive low-severity fires better than its competitors because it has thicker bark and deeper roots. It readily recolonizes large, stand-replacement burns because its seeds are transported from distant stands by Clark's nutcrackers. The nutcrackers can disperse whitebark pine seeds up to 100 times further than wind can disperse seeds of subalpine fir and spruce (Tomback and others 1990). Most whitebark pine regeneration is from unexcavated seeds that germinate and grow (Keane and others 1990). The nutcracker prefers open sites with many visual cues for seed caching, much like the conditions after stand-replacement fires.

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Restoration Treatments

Suggestions for restoring damaged whitebark pine communities include cutting trees that compete with whitebark pine, prescribed burning, and planting of rust-resistant seedlings. However, these practices have not been demonstrated or tested in research studies (McCaughay 1990). Three study areas in western Montana have been selected to investigate the effect of silvicultural and burning treatments on whitebark pine growth response and regeneration: Coyote Meadows, Smith Creek, and Snow Bowl (fig. 1). These areas were historically dominated by whitebark pine, but the species is currently experiencing an increase in blister rust infection and mortality, as well as a corresponding accelerated successional replacement by subalpine fir.

Since each study area is different in terms of tree composition, structure, and site conditions, we developed different sets of treatments for each study area. Fundamentally, all treatments involve the use of tree cutting and prescribed fire to accomplish study objectives. However, implementation differs by sample area and treatment site. Silvicultural treatments being tested include release cuttings, fuel enhancement, thinning, and tree understory removal. Differences in burning include no burn treatments, burns in natural fuels, burns in natural plus augmented (for example, slash) fuels, and burns in young and old stands.

Each treatment was designed to be implemented by Forest Service Ranger District personnel in an operationally feasible manner. No special cutting or burning methods unknown to District personnel are proposed. If feasible, merchantable material cut on the study area that is not needed for fuel enhancement can be harvested using low-impact techniques.

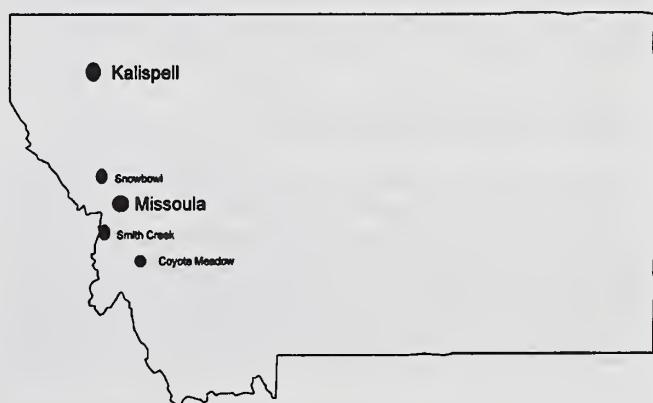


Figure 1—Map of Montana, U.S.A., showing locations of three whitebark pine study sites.

Coyote Meadows Study Area

The Coyote Meadows Study Area is within and adjacent to a 1960's logging unit on the 8,000 foot ridge in the Bitterroot National Forest southeast of Hamilton, Montana. The site originally supported a forest of large, mature whitebark pine mixed with lodgepole pine (*Pinus contorta*), spruce, and subalpine fir. White pine blister rust infections are common in and around the study area, but have not yet caused extensive mortality. The cut-over area was logged in an overstory removal treatment with no subsequent site preparation or burning, and as a result, it is dominated by patches of small subalpine fir, many of which pre-date the logging.

The study areas have been divided into five treatment areas. Treatment area 1 is in a clearcut area with a low density of subalpine fir regeneration, and treatment area 2 has a high density of subalpine fir. Within this logging unit there is a 7 hectare stand of old, dying whitebark pine with an understory of subalpine fir (treatment area 3). Fire scars on the pines indicate this stand last underburned in about 1780. Presumably, coverage of competing subalpine fir would have been greatly reduced if fires had continued to occur at a rate of one per century. This unlogged stand also experienced heavy mountain pine beetle mortality starting about 1927. Adjacent to the logging unit are two other study stands. One is a 300+ year old whitebark pine stand in which most whitebark pine trees are dead or dying, allowing fir and spruce to dominate the understory and replace them in the overstory (treatment area 4). The other is a portion of this old stand that burned in a stand-replacing wildfire in 1919 (treatment area 5). The burn now supports a vigorous young stand of young whitebark pine, lodgepole pine, subalpine fir, and spruce.

Each treatment area has an untreated control unit and one or two silviculture and/or fire treatment units. Treatment area 1 (low-density fir site) will be broadcast burned with no fuel enhancement treatment. Treatment area 2 (high-density fir site) will be broadcast burned with and without silvicultural cuttings to enhance fuel loadings to improve fire spread (for example, fuel enhancement treatments). Subalpine fir and spruce will be cut and allowed to cure to affect a more continuous fuel bed. Treatment area 3 (mature whitebark pine stand) will be underburned with and without fuel enhancement cuttings. Treatment area 4 is another mature whitebark pine stand that will receive release silvicultural cuttings performed at two densities (high and low). Treatment area 5 (70 year old whitebark pine) will be treated with the same release cutting to high- and low-residual density (McCaughey 1990).

Smith Creek Study Area

The Smith Creek study area occupies a subalpine site at 7,000 to 7500 feet elevation northwest of Hamilton on the Bitterroot National Forest. Whitebark pine was once a major seral component of this forest along with minor amounts of lodgepole pine, subalpine fir, and spruce. Whitebark pine saplings have become established in a 1968 clearcut adjacent to the study area; however, approximately

90 percent of the live, mature whitebark pine are infected with blister rust and 20-30 percent of the whitebark pine have died in recent years. Subalpine fir is rapidly replacing whitebark pine and lodgepole pine.

Three treatments and a control are implemented on a 9 hectare stand in this demonstration area. Treatment 1 is a prescribed underburn that will somewhat mimic a natural underburn in whitebark pine. Burning will be done in late summer or early fall. A small amount of felling of subalpine fir may be done prior to burning to provide some red slash to promote fire spread.

Treatment 2 is the creation of small openings. Circular openings in the forest canopy will be created (50 meter diameter, 0.2 hectare) by removing all trees to encourage whitebark seed caching by the Clark's nutcracker. Additionally, all subalpine fir, spruce, dying lodgepole pine, and dying whitebark pine trees will be removed from areas adjacent to the openings leaving an open stand of whitebark pine and lodgepole pine. Slash will be piled in the openings and burned. If feasible, the areas surrounding these openings will be underburned.

Treatment 3 is the creation of openings similar to treatment 2 but without the burning of slash.

A companion study will be conducted on this study site by University of Montana graduate student Janet Howard with Dr. Ragan Callaway. Seedlings from apparent rust-resistant and nonresistant phenotypes will be grown from seed obtained from Ray Hoff, Geneticist, Forest Sciences Laboratory, Moscow, Idaho. These seedlings will be grown in a nursery and planted after 2 years in the nutcracker openings in both burned and unburned treatments (treatment areas 2 and 3). Rust resistance, tree survival, and tree growth will be compared across these openings. Regeneration success and subsequent growth will be measured in relation to treatment microsites (different burn severities and unburned conditions). Density of natural regeneration will also be measured for several years.

Snow Bowl Study Area

The Snow Bowl study area lies about 10 air miles northwest of Missoula, Montana in the Snow Bowl Ski Area on the Lolo National Forest. Elevation ranges from 7,200 to 7,900 feet and aspects are mostly southeast. Treatment blocks within the study area lie mostly between proposed ski runs in tracts of 2 to 3 hectares. This area is experiencing extensive tree mortality with approximately 60 to 80 percent of the overstory whitebark pine killed by blister rust (Keane and Arno 1993). Subalpine fir is increasing in the understory and overstory as a result of this mortality. However, there are large patches of whitebark pine regeneration (2 meters tall, 20+ years old) in the study area that have not yet been severely impacted by the blister rust.

Three treatments and a control are proposed between ski runs within the Snow Bowl site. Since this study is still in the planning stages, details of treatment location and implementation are currently lacking. The three proposed treatments are prescribed burn, thinning and prescribed fire to favor whitebark pine, and thinning without fire.

Study Methods

In all three study areas, permanent sample plots will be located in each treatment area. These plots will be used as the basis for fuel, vegetation, and natural and artificial regeneration measurements (table 1).

Many attributes will be measured to study the treatment effects on whitebark pine growth and regeneration. Whitebark pine seedlings will be counted in microplots within treatment area macroplots for approximately 5 to 10 years. Vascular plant development and changes in ground cover will be measured using microplot techniques. Long-term fire effects on tree growth will be monitored from tree cores taken 5 and 10 years after the burn. Fuel consumption will be calculated by measuring fuel loads, duff depths, and litter depths before and after the burn (Brown 1970; Brown and others 1982). Selected macroplots will be photographed semiannually to illustrate vegetative development following treatment. Leaf area indices will be estimated using the LiCor LAI-2000.

Stand Replacement Prescribed Fire

The low intensity treatments presented in this study attempt to reestablish whitebark pine at the stand level. These treatments are generally, but not specifically, designed to mimic low-severity underburns common in dry whitebark pine forests. However, there are many whitebark pine forests where fire burned entire landscapes in stand-replacement fires (Arno 1986, Keane and Arno 1993). Whitebark pine has a distinct advantage in colonizing these large burns because of the great seed dispersal distances provided by the Clark's Nutcracker. The nutcracker can disperse whitebark pine seed much further than wind can disperse subalpine fir seed (Schmidt and McDonald 1990).

Currently, most whitebark pine stands in the stand-replacement fire regime of the upper subalpine zone are rapidly becoming dominated by subalpine fir due to accelerated succession caused by the rust. These landscapes must have fire reintroduced at an unprecedented scale to mimic

the ecological processes that resulted in whitebark pine dominance prior to European settlement (Brown and others 1994). A viable restoration treatment is a prescribed stand-replacement fire that burns a large land area (>1,000 hectares).

The main objective of the prescribed stand-replacement fire is to create a burned area so large that wind-dispersed seeds only land on the perimeter of the burn. This intense fire can be small (300 to 1,000 hectares) if the fire burns from the bottom to the ridgetop on landscapes where wind will not disperse subalpine fir seed into the burn. An operational prescribed burn of 200 acres is planned for the summer of 1996 on the Bitterroot National Forest and a few such burns are planned for 1997 on the Kootenai National Forest.

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Table 1—Stand characteristics sampled on each plot pre- and post-treatment.

	Sampling schedule	
	Pre-treatment	Post-treatment
Canopy coverage vascular plants	X	X
Tree seedling size and density	X	X
Overstory tree characteristics	X	X
Down woody fuel loadings	X	X
Litter loadings	X	X
Duff depth	X	X
Ground coverage (duff/mineral soil)	X	X
Release cutting measurements		X
Regeneration measurements		X

Examples of Fire Restoration in Glacier National Park

Laurie L. Kurth

Covering just over 1 million acres, Glacier National Park straddles the Continental Divide in northwestern Montana. Diverse vegetation communities include moist western cedar-western hemlock (*Thuja plicata-Tsuga heterophylla*) old growth forests similar to those of the Pacific Coast, dry western grasslands and prairies, dense lodgepole pine forests (*Pinus contorta* var. *latifolia*), ponderosa pine (*P. ponderosa*) savannas, mixed conifer forests, and alpine and subalpine meadows. The diversity and complexity of the park's vegetation and wildlife necessitates innovative, long-term, and holistic management based on scientific knowledge. Fire history studies and records show that much of the park west of the Continental Divide has burned since the mid-1800's (Barrett and others 1991). Moreover, fire has been an essential process in defining vegetation communities and mosaics in the park for centuries and probably for millennia.

Glacier National Park was established by Congress in 1910, a year of widespread fire activity in the western United States. In response to the catastrophic fire season, full fire suppression became the policy for Federal lands, including the park. Little was known regarding fire behavior and its role in the park's ecosystem. Concern that fires would burn precious resources in or out of the park was reinforced in the 1920's and 1930's when a few fires burned structures in the park and quickly ran onto adjacent lands. Suppression efforts were effective in extinguishing small fires early in the century and nearly all fires by the middle of the century.

By the late 1970's, fire was recognized as an important process, and policies began to shift toward allowing and possibly igniting fires in Glacier National Park (Glacier National Park 1977). An 80 acre experimental fire in 1983 in a ponderosa pine community was the first significant fire ignited to restore fire and fire effects to a system that was suffering from 70 years of fire exclusion. A goal of that fire was to help maintain and regenerate ponderosa pine, and the fire did kill approximately 60 percent of the competing young Douglas-fir (*Pseudotsuga menziesii* var. *glaucia*) and spruce (*Picea engelmannii*) (Kilgore 1986). Although the fire was successful in accomplishing several goals, it wasn't until 1992 that park personnel ignited fires again.

Fire exclusion policies in the park and on adjacent lands have led to current fire-free intervals of more than 60 years. Comparison of aerial photographs from the 1940's, 1960's and 1980's demonstrated obvious decreases in the extent of grasslands near the western park border. Without frequent

fire, numerous lodgepole pine trees have become established in these grasslands. In 1992 and 1993, fire was ignited in approximately 180 acres of grassland. Lodgepole pine tree mortality was the primary objective of burning as well as nutrient cycling and promotion of native grasses and forbs. Three years following the burning, mortality of 90 percent of the trees was observed. Therefore, the mortality objective of the burns was accomplished. Successive use of fire, both through lightning and management ignitions, is planned in these grasslands on a rotational basis.

Prescribed natural fire policy (limited or no suppression of some lightning-ignited fires) was also adopted in the late 1970's; however, no lightning ignitions were actually allowed to burn until 1987. Climate in Glacier National Park is such that much of the area remains too moist to burn even while other areas in the Rocky Mountains are experiencing a very active fire season. When lightning ignitions occur, they frequently require suppression because the wildfire activity is at a high level in the surrounding regions and few personnel are available to support prescribed natural fires.

Following the nationally catastrophic 1988 fire season, Glacier National Park adopted a new fire management plan with the entire park divided into four prescribed natural fire zones (Glacier National Park 1991). Weather, fire behavior, smoke production, and socio-political factors formulate the "prescription" for burning, which is very restrictive along the borders and in high visitor use areas while it is fairly liberal near the Continental Divide. Since 1991, the park has allowed several prescribed natural fires. Most lightning ignitions in high elevations west of the Continental Divide have been allowed to burn with careful and constant monitoring.

A June ignition near the Park's west boundary in 1994 was declared a prescribed natural fire. Named the Howling Prescribed Natural Fire, it burned less than an acre over a 4 week period. Toward the end of July the fire became more active and the national fire season was very active. Numerous issues surfaced, including: appropriateness of a prescribed natural fire during a busy fire season when few personnel were available; appropriateness of suppressing a natural ignition in a natural area that burns primarily during active fire seasons; ability of a land management unit to manage a large, lengthy fire without assistance; and appropriateness of requiring all new ignitions regardless of location and burning conditions to be "suppression" fires during an very active fire season (Zimmerman and others 1995).

With the use of emerging technology to predict long-term fire spread and behavior (RERAP and FARSITE computer programs), it was demonstrated that the Howling Fire posed no threat to exceed previously determined boundaries. Thus it was allowed to remain a prescribed natural fire. Fire experts throughout the West came to Glacier National Park

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to observe the fire, resolve socio-political concerns, and ensure the fire's success. Persisting through 4 months, burning approximately 2,000 acres and requiring less than \$200,000 to manage, the Howling Fire has demonstrated the practicality of prescribed natural fires.

Fire restoration in Glacier National Park has evolved slowly. Success of prescribed fire from management and natural ignitions over the past decade is leading toward the return of fire to its natural ecological role in the Park. Currently, a 5 year management plan for management-ignited fires calls for burning over 2,000 acres of prairie and ponderosa pine communities and planning for large-scale, mixed severity fires (Barrett and others 1991; Glacier National Park 1993). Fire is now recognized as an important process and a tool for management. However, we must continue to support the philosophy that fire is an important natural resource process that warrants a substantial commitment to maintain it. Although it has had a slow start, fire restoration in Glacier National Park is becoming a reality.

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Dealing With Public Concerns in Restoring Fire to the Forest

Leslie A. C. Weldon

Public support is important to all restoration efforts on public lands. Some types of restoration activities are easier for the public to support than others. Restoring wetlands, habitat restoration for salmon or burrowing owls, and vegetative rehabilitation are generally acceptable practices. Most restoration projects and activities such as these do not have much direct impact on people. However, restoring ecological processes, such as fire, is a different story. In this paper, I describe the challenges of restoring fire to the forest. I share some of the opinions of people in the Bitterroot Valley of western Montana regarding management ignited prescribed fire, and examine some of the major barriers to public acceptance. I also suggest ways to increase public support for fire restoration—concepts that should be part of every fire restoration effort.

Federal land managers are responsible for ensuring the long-term health and sustainability of forests and grasslands by using the best scientific information available. As is evidenced by decades of research and over a century of experience, the best scientific information has told us that fire is key to maintaining long-term sustainability of most ecosystems in the Western United States.

While prescribed fire is not a new tool in forest management, the sizes and frequencies recommended by scientists and managers to meet ecological goals are new, and they are highly controversial. In many places, certainly in the Bitterroot Valley, the emotions surrounding wildfire or management ignited fire are as passionate among those against it as they are among those who support it.

Background

As part of the Bitterroot Ecosystem Management Research Project, a social assessment was conducted by Sociologist Dr. Janie Canton-Thompson, director of the Bitterroot Social Research Institute. This social assessment involved in-depth interviews with opinion leaders and focused on management of the Bitterroot National Forest and use of prescribed fire. The Bitterroot Valley, located in Ravalli County, Montana, is surrounded by National Forest land. In 1995, Ravalli County was listed as the second fastest growing county in the state of Montana. People are coming to the valley in part because of its natural beauty which contributes to the quality of life that so many newcomers are seeking. These are the same qualities that "native

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Bitterrooters" have enjoyed for generations. The valley communities are going through significant changes. The values, concerns, wants and needs relating to natural resource management are complex.

Prescribed fire currently receives mixed support among residents of the Bitterroot Valley. The following excerpts are quotes made by interviews for the "Social Assessment of the Bitterroot Valley, Montana with Special Emphasis on National Forest Management" (Canton-Thompson 1994).

"...they should mix it in with other activities so they don't have to put all that fiber into smoke. They should use what they can and then burn what's left over."

"Use management ignited prescribed fire as a last resort when there is no other way to gain your objective."

"I believe there's a place for it...but actually getting it done in a practical fashion is another thing altogether."

"Prescribed fire does the same as natural wildfire, but you can control it under good conditions. Using it managed is better than nature doing it when conditions are bad."

"I'm kind of reserved about it, and I would have to be shown it really helped to believe it."

"In fact, I'm always bewildered when I see prescribed fires happening. I never know what the Forest Service is doing. I'm always confused when I see prescribed burns...Maybe they're doing a good thing, but I don't know about it...[It] irritates people in the fall to see the Forest Service doing burns upon the sides of the mountain because those fall days are the best."

Challenges to Successful Fire Restoration

Mixed Messages About Fire

Smokey Bear recently celebrated his 50th birthday. This anniversary marks 50 years of one of the most successful public information campaigns ever launched. Smokey and his fire prevention message are part of our culture, and still remain popular in American society. Smokey's message worked hand-in-hand with a highly effective fire suppression organization that met the fire exclusion goals of minimizing loss of forest resources to wildfire. However, fire exclusion has caused substantial interruption to natural ecosystem function across most of America's wildlands. Fire suppression still has a role in protecting resources and property. Although it is a critical ecological process, we can't let it operate unmanaged and unmonitored. The suburban-wildland interface areas are places where fire suppression continues to dominate. However, support is growing to permit some fires to burn, and for management ignited prescribed fires for natural resource management.

A key message for the public is that even as we work to restore fire on the landscape, the commitment to protecting lives, property, and resources through fire suppression will continue.

Understanding of Fire's Role in Forested Ecosystems

Over the last 7 years since the spectacular 1988 fire season, the public, particularly in the West, has become more aware of the role of fire. But we have much work to do here, and much to gain from people achieving a better of understanding of the ecological role of fire processes. The use and role of fire will then make better sense to them, and will become more familiar and acceptable.

Perceptions of Wood Fiber Waste

As is evident in the quotes from the social assessment, wood fiber waste from prescribed fires is a key concern. This is especially true in communities where forest products are a source of income, or a source of heat. Waste is not good. But prescribed fire burns wood fiber and kills some trees. In many cases, this loss is expected as part of meeting burn objectives, but loss of wood fiber also occurs when fire intensity is higher than expected or when escaped fire occurs. It is frequently not economically feasible to extract, haul, and utilize woody biomass within the constraints of existing transportation systems and low market values.

Effects of Prescribed Fire Smoke on Visual Quality and Human Health

Smoke affects people. To some, it is a minor annoyance, for example, in producing haze that degrades the visual quality of a sunny day. To others, smoke can seriously aggravate preexisting respiratory conditions. Smoke from prescribed fires can alter air quality over large areas. The other visual quality effect is that of the fire on the landscape. To many people, burned landscapes are not attractive and detract from the aesthetic values of an area.

Interacting With the Public

None of these challenges can be resolved without directly interacting with the public and communities who are affected by prescribed fire. Strategies, goals, and objectives for public involvement should be part of the process for planning and implementing fire restoration programs. The people interviewed in the Bitterroot Social Assessment expressed their needs and made many recommendations for improving the acceptability of management ignited prescribed fire. By building support for their programs, managers can be more successful in meeting prescribed fire management goals. Managers must talk, listen, and respond to the public.

Talk to the Public About Fire in Ecosystems

Ecological Facts—Develop simple ways to present ecological processes and interactions. Field trips, media features, demonstrations, and publications are examples of activities that stimulate interest, interaction, and dialog.

Benefits—Help individuals to understand the benefits of fire in ecosystems as it relates to biological diversity and forest sustainability, wildlife populations, and watershed productivity.

Consequences—Personal interactions through field trips allow people to see fire relationships and the effects and consequences of fire suppression for themselves. Trade-offs between wildfire and prescribed fires in suburban interface areas with high fuel buildups are particularly important to explore with the public. Proactive management through prescribed fire becomes an important tool for public consideration once its role in reducing risk in interface areas is understood.

Risks in Implementing Prescribed Burns—Agencies need to be open and honest about our technical abilities and limitations in prescribed fire management. Much can be gained in public support by taking time to explain goals for prescribed burning projects as well as how burning projects are designed and implemented. But, at the same time, we should acknowledge the risks associated with management ignited prescribed fire, and that the risk of escaped fires can be minimized, but not eliminated.

Listening to the Public Concerns

It is equally important for managers to acknowledge what we hear from the public. Trust, respect, and credibility develop in relationships when needs and concerns are validated. Validation also occurs when the public is involved in developing goals for restoring fire processes. This involvement needs to occur at both the planning and project levels.

At the planning level, public input will play a key role in identifying levels of prescribed fire that are socially acceptable. Compromise among managers, scientists, and the public will help establish the rate at which fire restoration goals can be achieved at landscape scales.

Involving the public early in designing site specific projects can also improve public support at the project level. Public participation at this level gives managers the opportunity to answer questions related to the technical aspects of implementing a prescribed fire project. Information about goals, expected fire behavior, desirable burning conditions, and monitoring can best be shared with the public through a single project. The awareness gained can result in support for future efforts.

Be Responsive to Public Concerns

In addition to a poor understanding among members of the public of ecological objectives for using prescribed fire,

managers can, and must, continue to respond to other public concerns—for example, wood fiber utilization and smoke management. Concerns about wood fiber waste can be addressed by ensuring that alternatives that optimize the economic benefits of any available wood fiber are considered. This is already a consideration for many projects where fuels reduction through thinning or commercial harvest is done in conjunction with prescribed burning in order to meet restoration objectives.

Concerns about smoke effects can be mitigated by alerting the public of upcoming burning activities including the purpose, best conditions for ensuring good smoke dispersal, duration, size, and location of projects. Although it is impossible to reach everyone, using local radio, print, and television media can provide broad coverage. In many instances, public interest is enhanced once projects are underway. Contacts made to agency offices can be treated as opportunities to share more about the prescribed fire program, and to gather additional input from concerned or interested citizens.

Conclusions

The goal is to restore ecological health and productivity to forests in the West by the expanded use of fire as a management tool. Active public support is critical to success in reaching this goal. Managers must place a priority on public participation as a key step in planning and implementing a growing prescribed fire program. Social assessments, such as the one completed in the Bitterroot Valley, are tools for understanding public attitudes, concerns, and suggestions regarding prescribed fire programs which, in turn, can lead to effective partnerships in building support.

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Restoration in Pacific Westside Forests



Fire History and Landscape Restoration in Douglas-fir Ecosystems of Western Oregon

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For thousands of years fire has been a major, natural disturbance in the forest landscape from the Cascade Range westward to the coast in Oregon and Washington (Agee 1993; Brubaker 1991). Viewing the landscape of the central western Cascades in Oregon from a high point, one can see that fires of variable intensity and areal extent have created a complex mosaic of forest patches (Morrison and Swanson 1990).

In the past, fire was an integral part of the ecosystem, affecting wildlife habitat, forest stand dynamics, soil properties, and watershed hydrology. Even nineteenth century observers Gifford Pinchot and John Muir recognized the profound importance of fire in these forests (Pinchot 1899). They noted that the most obvious fire effect was the abundance of the west-side Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Large Douglas-fir trees are much more fire-resistant than competing species, such as western hemlock (*Tsuga heterophylla*), which gradually replace the fir in the absence of fire or other major disturbance. Large Douglas-fir have often survived repeated low- to moderate-intensity fires over the centuries (Morrison and Swanson 1990). Douglas-fir also benefits from severe fires since it readily recolonizes heavily burned landscapes (Agee 1993).

Fire suppression since the turn of the century and logging since about 1950 have changed the extent and role of fire on public lands in Oregon's west-central Cascades (Morrison and Swanson 1990). In these landscapes, the historic fire regime has generally been replaced by (1) fire exclusion and patch clearcutting or (2) fire exclusion and no logging, as in "natural" areas. This paper deals primarily with restoration concerns in the landscapes with previous patch clearcutting, but some of our findings also pertain to restoration of the fire process in unlogged forests.

Exclusion of fire (Pyne 1982) and its replacement by patch clearcutting (Spies and others 1994) as the major disturbance type have affected forest ecosystems over millions of hectares in western North America. Recently, attention has been focused on effects of the resulting changes in landscape patterns and potential approaches to reduce some of the undesirable effects on habitat (Harris 1984; FEMAT 1993).

Harris (1984) described approaches that include conserving old-growth forests and working to connect it with corridors, but did not try to apply this to a particular landscape. FEMAT (1993) developed a plan based primarily on reserves and rather fixed prescriptions for surrounding lands. FEMAT did not prescribe restoration of natural-fire-created landscape patterns, except to the limited extent that may be accomplished by old-growth forest reserves. Restoration of fire and concomitant benefits to stand structure and composition, fuels, and forest health have received recent attention (Wright and Bailey 1982; Walstad and others 1990). Though restoration ecology has seen significant recent advances focused on the site scale (Jordan and others 1988), landscape-level restoration is not well developed in concept or practice (Baker 1994).

We discuss the range of scales of fire effects and present the Augusta Creek Project as an approach to restoring fire-created landscape patterns to portions of a landscape in which timber harvest is allowed in the Northwest Forest Plan.

Scales of Fire Effects

Fire affects ecosystems at the microsite to continental scales. We will briefly discuss the stand to landscape scales of fire effects in the western Cascades of Oregon. At the local site scale, fire effects include altered stand composition and structure, nutrient cycling, and other system components. Fire can kill none, part, or all of the plants in different canopy layers, consume varying amounts of the forest floor and heat the soil to a wide range of temperatures, depths, and durations. Vegetation composition and structure of the succeeding stand are controlled by the surviving plants and the organisms that they and other site conditions allow to colonize.

At the hillslope scale, fire may create landscape patterns by leaving many more survivors in a moist riparian zone or north slope than on a drier south slope or ridge, and it may leave no survivors in a steep draw where upslope winds fan flames and convex topography concentrates heat.

At a small landscape scale, fire occurs at varying frequencies and creates a mosaic of patches and corridors of varying amounts of surviving vegetation. Morrison and Swanson (1990) have documented this for the Deer Creek area in the western Oregon Cascades (fig. 1). Similar patterns are found in the Augusta Creek Project area.

At a large landscape scale, we know little about the spatial age patterns in stands created by the natural fire regime. At

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Figure 1—Spatial variation in fire severity as reflected in tree mortality, 1800-1900, in the Cook-Quentin study area of Morrison and Swanson (1990).

this scale in the Pacific Northwest, fire regimes probably vary significantly. Examples would be across part of the Cascades from the foothill forests adjacent to the Willamette Valley to the crest of the Cascades.

Patterns at all these scales are important to wildlife habitat, stream habitat, biomass productivity, and landscape susceptibility to future disturbances such as floods. Baker (1994) has examined ways in which fire could be reintroduced to create landscape patterns similar to the natural ones, but reintroduction of fires of large historic sizes (100-10,000+ ha) is not possible outside wilderness areas and parks in this region. Even within the larger parks where prescribed natural fire policies have been adopted, fire size and severity are greatly constrained. The Augusta Creek Project examined one way tree cutting can be used in place of fire to produce a dynamic landscape with some of the important natural landscape features obscured by fire suppression and lost by the pattern of clearcuts. We do not claim that timber cutting can fully or adequately replace the role of fire. Broadcast burning in conjunction with harvest cutting can return some of the effects of fire, but we have not yet considered this option. Perhaps if land managers begin applying fire to more of the landscape, as suggested by Williams (1995) and Mutch (1994), this treatment can be added.

The Augusta Creek Project

A landscape analysis and management plan, based on the disturbance regime prior to Euroamerican settlement, were developed for the 7,700 ha Augusta Creek area (Cissel and others 1994; Cissel and others, in preparation; Wallin, in press). About 50 percent of the project area is protected as Wilderness, Roadless Area, Wild and Scenic River Corridor, lands having unstable soils, and special elk management areas in the Willamette National Forest Plan. We did not consider changing their designation or cutting in these areas. We developed an alternative management plan for the remaining area including changes to the riparian reserve system designated in the Northwest Forest Plan (Espy and Babbitt 1994). This landscape design includes a mixture of approaches—wilderness area management, species conservation, landscape restoration, and commodity production—distributed in various combinations across the landscape.

Goals and Assumptions

There is a growing awareness that to sustain human uses of an ecosystem, the ecosystem itself must be sustained. Our main goal in the Augusta Creek Project was to develop a landscape management approach that used past landscape conditions and disturbance regimes to provide key reference points and design elements for future landscape objectives (Swanson and others 1993), while meeting the objectives of the Northwest Forest Plan (Espy and Babbitt 1994). A premise of this approach is that native species have adapted to the dynamic changes of habitat patterns resulting from disturbance events over thousands of years, and the probability of survival of these species is reduced if their environment is maintained outside the range of historical conditions. Similarly, ecological processes, such as nutrient and hydrologic cycles, have historically functioned within a range of conditions established by disturbance and successional patterns. Management activities that move structures and processes outside the range of past conditions may adversely affect ecosystems in both predictable and unforeseen ways.

A second key component of our management strategy recognizes that existing conditions must be integrated with this historic template to meet long-term objectives. Human uses (for example, roads in riparian areas, widespread clearcutting, a major dam, and portions of a designated Wilderness and unroaded area) have substantially altered conditions in the project area and in the surrounding watersheds.

Analytical Process

Our analytical process involved four sequential phases as summarized below. Results from any one phase, however, could trigger a return loop to a preceding phase. Work in each of these phases was conducted in the context of the larger surrounding watersheds and was designed to link to management activities.

In the first phase, past and current conditions, processes, disturbance regimes and human uses were analyzed. The larger context of the surrounding watersheds was taken into account. This watershed analysis was similar to watershed analyses being implemented as part of the Northwest Forest Plan (Espy and Babbitt 1994).

In the second phase, results from the first phase of the analysis were used to develop landscape management objectives and prescriptions for specific portions of the planning area. Landscape management objectives are qualitative and quantitative statements that describe conditions we wish to see across the landscape in the future. These objectives were based on the range of "natural" variability of forest conditions as interpreted from fire and other disturbance history studies, and modified where current conditions were outside the range of past conditions. In areas where timber cutting was allocated, landscape objectives were translated into prescriptions that established cutting frequencies, intensities, and spatial patterns. These objectives were based largely on natural fire frequency and severity and the resulting spatial patterns. General prescriptions for low-severity fire were also developed.

In the third phase, landscape objectives and prescriptions were used to develop spatially and temporally explicit portrayals of potential future landscape and watershed conditions. Spatial pattern objectives were used to map blocks, termed "landscape blocks," where timber cutting and prescribed fire will occur. These blocks were used for long-term timber harvest scheduling according to the prescribed frequency and intensity of cutting for each landscape area. Maps of forest composition and structure were then projected for 400 years, using a 20-year time step.

In the fourth phase, these maps were used to evaluate a wide range of ecosystem processes and indicators including landscape composition and pattern, plant and animal habitat, and human uses. A combination of quantitative and qualitative methods were used to compare the new landscape design to conditions that would result from application of standards, guidelines, and assumptions in the Northwest Forest Plan (Espy and Babbitt 1994) prior to adjustments based on watershed analysis.

Phase 1—Analysis of Conditions, Processes, and Uses

A fire history study revealed fire patterns within the planning area over the last 500 years. Plot-level dendrochronologic data collected with the methods of Morrison and Swanson (1990) were used to map 26 fire events (fig. 2). The fire-event maps and field observations were used to describe and map fire frequencies, severities, and spatial patterns of nine general, fire-regime mapping units (fig. 3). The fire event maps were also used to reconstruct and analyze vegetation patterns within the same 500-year period so they could be compared with managed patterns.

Several approaches were used to analyze the aquatic system and hillslope-to-stream connections (Cissel and others, *in preparation*). Past landslides and debris-flows and relative potential for future occurrences of these events were mapped from aerial photographs, existing maps, and field surveys. Relative susceptibilities of the landscape to rain-on-snow peak flows and contributions to summer base flows were mapped. A time-series analysis of aerial photographs spanning the past 40 years were used to assess riparian vegetation dynamics and disturbance history.

Both prehistoric and contemporary human uses were described and mapped (Cissel and others, *in preparation*). Prehistoric and historic data for the general area were employed to construct a map showing probability of past use by native people. Current human uses include hiking (two trails), camping (three campgrounds), angling, hunting, and harvest of timber and special forest products (for example, ferns and other greenery for the floral industry).



Figure 2—Fire episodes by century in the Augusta Creek study area (Cissel and others, *in preparation*).

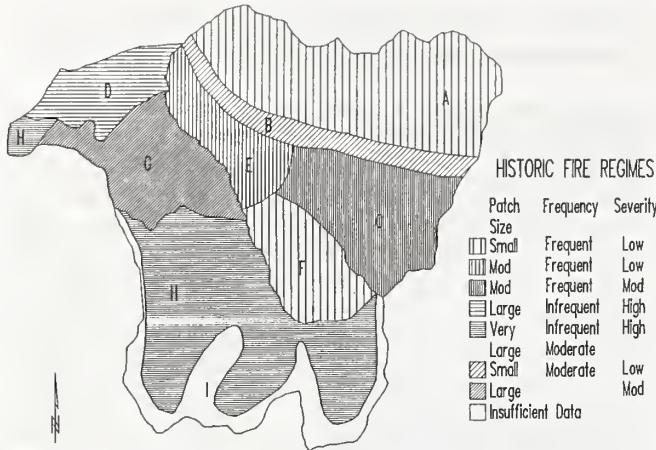


Figure 3—Fire regimes from the fire history study (Cissel and others, in preparation).

Phase 2—Landscape Objectives and Prescriptions

The planning area was subdivided into three general categories so that specific landscape management objectives and prescriptions could be developed: (1) large reserves as specified by the Willamette National Forest Plan, (2) landscape Management Areas where timber harvest was prescribed, and (3) an aquatic reserve system.

Large Reserves—Several reserves were established in the Willamette National Forest Plan and they comprise about 50 percent of the Augusta Creek Study Area. Objectives and prescriptions for these areas imply a “natural” succession approach, with the exception of part of the unroaded area where active management was prescribed to maintain high-elevation meadows. Prescribed natural fires were encouraged where feasible.

Landscape Management Areas—Four Landscape Management Areas were established at the small landscape scale to reflect different fire regimes (fig. 4) in areas where timber harvest was allocated. Management objectives and prescriptions were described based upon the range of historic conditions. Rotation ages (100-300 years) were derived from fire frequency information; retention levels of trees to remain after treatment (15-50 percent) were based upon fire severity interpretations (fig. 4). Prescriptions for low-intensity fires were derived from fire regime descriptions and integrated with timber harvest patterns and schedules.

Landscape Blocks—Landscape blocks that reflect hillslope scale of the natural disturbance regime were established within Landscape Management Areas to provide a link to project (harvest unit) planning. Block size, boundaries, and the amount of green tree retention reflect natural fire patches (surviving trees) in those areas. Since all of one block is treated in one time period, large block size results in more interior habitat and reduced edge in comparison to the small cutting units of the dispersed cutting system used in the past decade.

Aquatic Reserves—Aquatic reserves were then established (fig. 4) based upon the likely frequency, intensity, and spatial pattern of future timber harvests, watershed processes, the larger surrounding context, and the degree to which the landscape has been altered by past human use (for example, dams, roads, timber cutting). These reserves were meant to be zones of minimum disturbance. We chose a reserve-system design that complemented the landscape objectives and was consistent with interpreted “natural” patterns. Small-watershed reserves comprised of both riparian and upslope habitats were positioned throughout the basin, such that different habitat types and topographic/disturbance regions were represented in headwater, mid-basin and lower portions of the drainage, and such that species of concern (for example, torrent salamander) were protected. Aquatic reserves included large riparian corridors along both sides of all major, valley-bottom streams (fig. 4). These

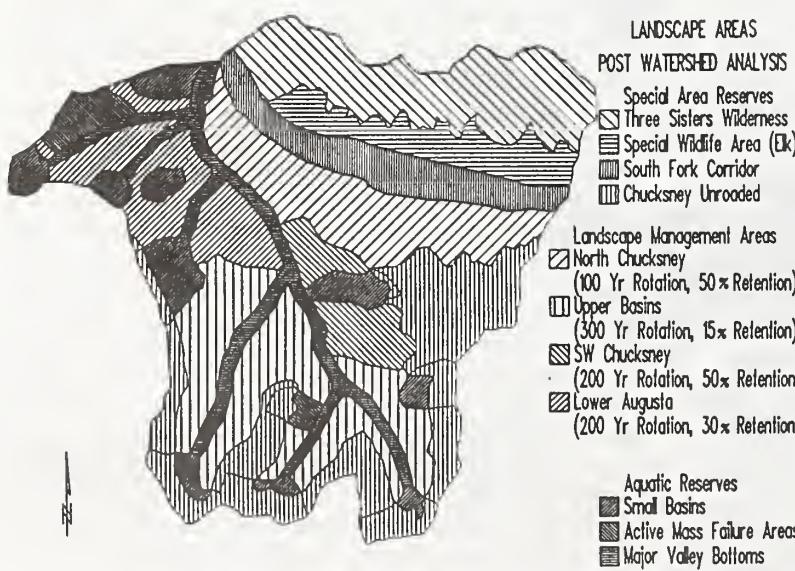


Figure 4—Landscape management areas under the Post-Watershed Analysis Approach (Cissel and others, in preparation).

areas, in which older forests survived past fire events, parallel the stream and include the stream, adjacent flood-plains, and riparian vegetation. These corridors link the small-watershed reserves.

Phase 3—Projection of Future Conditions

Maps of future landscape and watershed conditions were developed by simulating the growth of existing forest stands using a simple stand-age model in a Geographical Information System (GIS). Following timber cutting, blocks were reset to specific stand conditions, according to a timber harvest schedule determined by the landscape objectives and prescriptions for the area, and growth was simulated again until the next scheduled cutting. A set of maps depicting future landscape conditions for each 20-year time interval was generated for the next 400 years. These maps show a gradual change in the landscape from the relatively fragmented forest of today to one dominated by larger blocks and containing a wider array of stand types, as described in the landscape objectives. By year 100, the future landscapes appear significantly different from the existing landscape, and continue to gradually change before reaching a dynamic equilibrium in year 200.

Phase 4—Evaluation

We evaluated this landscape design, which we termed the Post-Watershed Analysis Approach, by comparing it to a future landscape generated by application of standards, guidelines, and assumptions in the Northwest Forest Plan (Espy and Babbitt 1994) prior to adjustments based on watershed analysis (Cissel and others, in preparation). This contrasting landscape design was dominated by the extensive Riparian Reserves buffering all streams, and an 80-year timber harvest rotation on most upland areas. Harvest areas maintained a relatively light level of green tree retention (15 percent). We evaluated landscape composition and pattern; amphibian, bird, mammal, fish, and aquatic processes; peak and low stream flows; disturbance processes (fire, wind, landslides, insects and diseases); and long-term timber yields using quantitative and qualitative techniques.

Effects on Landscape Pattern

Most differences between the two approaches resulted from the strikingly different landscape patterns. Larger patch sizes with a greater amount of interior habitat (lower amounts of edge) characterize the landscape developed under the Post-Watershed Analysis Approach in the area subject to timber cutting (figs. 5 and 6). This landscape pattern remains within the range of natural variability in terms of edge density and interior habitat whereas that of the Northwest Forest Plan Approach and a No Disturbance Approach (no logging and continued exclusion of fire) do not. This reflects treating relatively large landscape blocks and managing on long rotations in selected landscape areas in the Post-Watershed Analysis Approach to approximate, respectively, patch size and mean fire interval of the natural fire regime.

The No Disturbance Approach produces a landscape outside the range of natural variability by these measures (figs. 5 and 6). In a few decades it would provide no early successional or edge habitat. The No Disturbance Approach is shown only to compare landscape patterns and was not otherwise evaluated.

These graphs reflect only the 50 percent of the landscape outside of protected areas (wilderness, etc.) to better show differences in approaches. The management plan is for the whole study area and this is the scale at which organisms

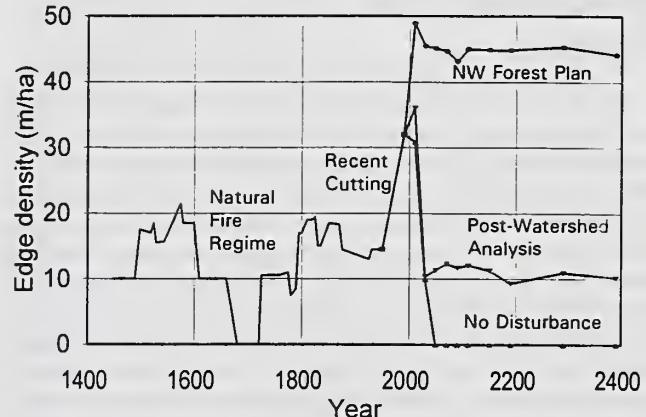


Figure 5—Temporal variation in edge density between open-canopy (0-40 years old) and closed canopy (>40 years old) forest over the last 500 years of the natural fire regime (pre-1970), during recent clearcutting (1970-1990), and under three potential future management approaches. This figure depicts changes only for the 50 percent of the study area outside of protected areas (wilderness, unroaded, etc.).

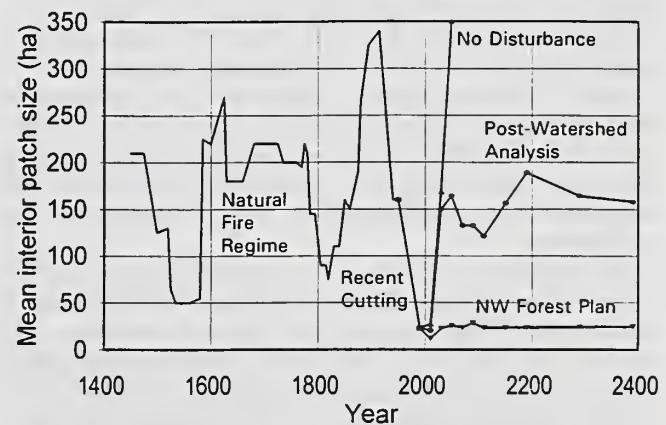


Figure 6—Temporal variation in interior habitat (inside a 100 m buffer) between open canopy and closed canopy forest as further defined in the caption for figure 5. Mean interior habitat for the No Disturbance Approach reaches 1,170 ha in 40 years and is not shown on the graph. This figure depicts changes only for the 50 percent of the study area outside of protected areas (wilderness, unroaded, etc.).

and processes with larger ranges and scales will perceive it. When the whole study area is included, the edge density of the Northwest Forest Plan and Post-Watershed Analysis Approaches equilibrate to about 36 and 17 m/ha, respectively, within 40 years. Note that the Northwest Forest Plan Approach is still outside the range of natural variability (as high as 50 m/ha). When the whole study area is included, mean interior habitat per patch under both approaches reaches 300 ha or more within 40 years. The large areas of reserves raise interior forest habitat to the upper end of the range of natural variability.

Effects on Forest Structure and Species

The Northwest Forest Plan and Post-Watershed Analysis Approaches were evaluated for effects on features in addition to landscape patterns. Under the Post-Watershed Analysis Approach, higher levels of habitat features, such as green trees, snags, and downed logs, would be found in patches where timber harvest occurs, and a greater range of habitat conditions would be distributed throughout the planning area. This results from the larger blocks, longer rotations, and higher levels of green-tree retention in areas where timber harvest is allocated, and less land in linear aquatic reserves. Greater numbers of microhabitat features in areas harvested for timber, greater landscape connectivity, more interior habitat, and more refugia were felt to benefit many amphibians, birds (including the northern spotted owl), and mammals in the Post-Watershed Analysis Approach.

In contrast, the Northwest Forest Plan Approach leads to a two-toned forest pattern in the 29 percent of the analysis area subject to timber cutting. Here old forests develop along all lower slope positions, while most upper slope positions contain relatively young, structurally simple stands. This results from an intricate network of sharp-edged Riparian Reserves, relatively short rotations, and relatively low levels of green-tree retention in the upslope areas. Maximum protection of aquatic systems from timber harvest was provided by Riparian Reserves along all streams. Edge-using species were found to benefit from this design.

Little difference between approaches was evident for many processes and species. Disturbance processes (for example, landslides and flood events), stream flows, aquatic processes, species that use a wide range of habitats, and long-term timber yields were very similar between the two approaches.

The Augusta Creek example incorporates important features of the natural disturbance regime and landscape pattern into a management plan. We did not attempt to recreate all features of the natural disturbance regime, however; to do so would have been impractical. Under the Post-Watershed Analysis Approach there will be less variability: riparian corridors will not be harvested and old-growth will not vary from 5-80 percent, as occurred under the natural fire regime. The large wildfires (>10,000 ha) that occurred occasionally will not be mimicked. Timber harvest will produce many fewer snags and downed logs than did natural fires. Also, minimal use of fire will occur, but that could change if manager capabilities and funding for prescribed fire improve.

Implementation Status

Project-level timber sale planning and watershed restoration projects have been initiated in the Augusta planning area. The interdisciplinary team is using this landscape analysis as a starting point and expects to implement as much of the Post-Watershed Analysis Approach as possible within the guidance of the Northwest Forest Plan (Espy and Babbitt 1994). It appears that full implementation may require amending the Northwest Forest Plan. The Blue River Ranger District is now working on a watershed analysis and plan for the Blue River watershed, similar to the one we describe here for Augusta Creek, for the Central Cascades Adaptive Management Area where no amendment will be required.

Conclusions

Clearly it is possible to incorporate important features of the natural disturbance regime, landscape pattern, and stand structures into management plans. We offer the Augusta Creek Project as an example, and a great variety of plans different from ours are possible. The basic concept is that management choices, such as frequency of silvicultural treatments, can be based to a significant extent on the corresponding attributes of the natural disturbance regime. The objective is to retain habitat with stand structures, spatial arrangements, and disturbance frequencies within the range of natural conditions. This, we assume, would retain native species if applied over adequately large areas.

The concept of managing landscapes within the range of past conditions and the associated implications for landscape pattern restoration have not been subjected to public discussion. Acceptance may be more likely where fire suppression has caused the greatest undesirable ecosystem changes. This could be indexed as the period of effective fire suppression divided by natural fire recurrence interval. In the near-term we need more landscape analyses and management plans, such as the Augusta Project, with follow-up implementation to test operability and effectiveness of these concepts.

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Forests of the Oregon Coast Range— Considerations for Ecological Restoration

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Jane Kertis
Pete Teensma**

The Oregon Coast Range supports some of the most dense and productive forests in North America. In the pre-harvesting period these forests arose as a result of large fires—the largest covering 330,000 ha (Teensma and others 1991). These fires occurred mostly at intervals of 150 to 300 years. The natural disturbance regime supported a diverse fauna and large populations of anadromous salmonids (salmon and related fish). In contrast, the present disturbance regime is dominated by patch clearcuts of about 10-30 ha superimposed on most of the forest land with agriculture on the flats near rivers. Ages of most managed forests are less than 60 years. This logging has coincided with significant declines in suitable habitat and populations of some fish and wildlife species. Some of these species have been nearly extirpated.

Our objectives are to: (1) compare the historical and current patterns and disturbance regimes (historic burning by Native Americans [Boyd 1986] is considered here to be part of the natural disturbance regime), (2) examine biodiversity of both of these patterns, and (3) discuss ways in which current management may be modified by including characteristics of the pre-cutting period to increase biodiversity in the modern landscape. The Northwest Forest Plan (Espy and Babbitt 1994) addresses the issue of biodiversity maintenance and restoration with heavy reliance on reserves. We outline elements of an approach that relies less on reserves and more on incorporating natural landscape dynamics into future management.

The Oregon Coast Range

The northern half of the Oregon Coast Range, where fire data are more readily available, comprises about 1.5 million ha, and is bounded by the Pacific Ocean on the west and the Willamette Valley on the east. The present discussion pertains to this area.

These ecosystems are at generally low elevation, with ridge systems usually 300 to 600 m. They are near the Pacific

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Ocean, so they are warm and often highly productive, compared to the Cascade Range and central Oregon forests. Isaac's (1949) site index map shows much more site class I and II land in the Coast Range than in the Cascades. In the summers, humid maritime air creates a moisture gradient from the coastal western hemlock-Sitka spruce (*Tsuga heterophylla-Picea sitchensis*) zone with periodic fog extending 4 to 10 km inland, through Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*)-western hemlock forests in the central zone to the drier interior-valley foothill zone of Douglas-fir, bigleaf maple (*Acer macrophyllum*) and Oregon oak (*Quercus garryana*).

Coast Range Fuels and Fire Behavior

In the Coast Range, high leaf areas give rise to large amounts of fine live fuels—foliage and branches of trees and shrubs. The relative warmth and moisture also leads to higher decomposition rates of dead fuels (Harmon, no date). Prolonged, dry east winds appear to play an important role in curing and drying live fuels. With continued drought, live fuels become dry enough to be a significant heat source instead of a heat sink when burning. This situation produces an abundance of fine fuels and under these conditions fires can be very intense, especially when fanned by warm, dry east and north winds.

Comparison of Pre-Cutting and Current Landscape

Very large fires were the main disturbance agents of the Oregon Coast Range (Agee 1993; Morris 1934). According to Teensma and others (1991), the first moderately reliable spatial information on size and ages of Coast Range forests dates back to about 1850. They document the four largest fires from 1848-1940 as being 324,000, 126,000, 121,000, and 93,000 ha in size. These fires created a few large patches that dominated the structure of the natural Coast Range landscape.

Maps made from aerial photos for a recent Federal lands assessment of the northern Oregon Coast Range provide a valuable opportunity to compare pre-logging and current landscape patterns (Bush 1995). On a 182,000 ha area that showed little harvesting in 1950 we removed effects of all

harvesting by filling in clearcuts with the forest type of the surrounding stands (fig. 1). This approximation to a pre-harvesting forest was dominated by one enormous patch of mature conifers. In contrast, in 1992 this same area was composed of hundreds of patches with none over 4,050 ha (fig. 2). Additionally, cutting had created a much broader range of seral stages and greatly reduced the mature conifer component.

Estimates of mean fire intervals (MFI) from forests in the Oregon Coast Range include 96, 183 (based on data from Teensma and others 1991), 230 (Agee 1993), 242 (Ripple

1994), 276, and 400 years. The shortest intervals represent the interior valley-foothill zone, and the largest intervals represent the coastal western hemlock-Sitka spruce zone.

We fit the Weibull time-since-fire model to data combined from Teensma and others (1991) 1850 and 1890 maps that reflect no harvesting and very little harvesting, respectively. The modeled fire cycle coefficient of 183 years is similar to the estimates of MFI from other sources. However, once a fire occurs, the area can reburn at short intervals. Some portions of the Tillamook burn burned four times in 19 years between the 1930's and 1950's.

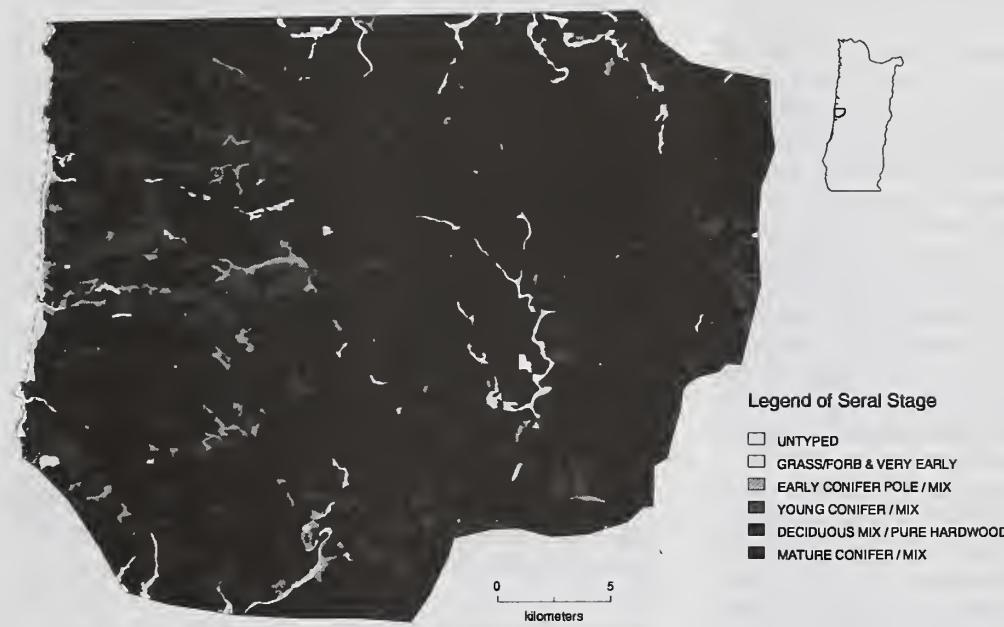


Figure 1—Seral stage map for a re-created pre-cutting landscape in the North Fork Siuslaw River area of the Federal Lands Assessment. Bush and others (1995) obtained the original map for a much larger area from the State of Oregon; it was based on interpretation of aerial photographs from approximately 1955. We took the portion of this map that showed the least cutting and assigned to the clearcut polygons the surrounding vegetation type. This was a straightforward process because clearcuts were almost always rectangles in mature forest and laid out in staggered settings.

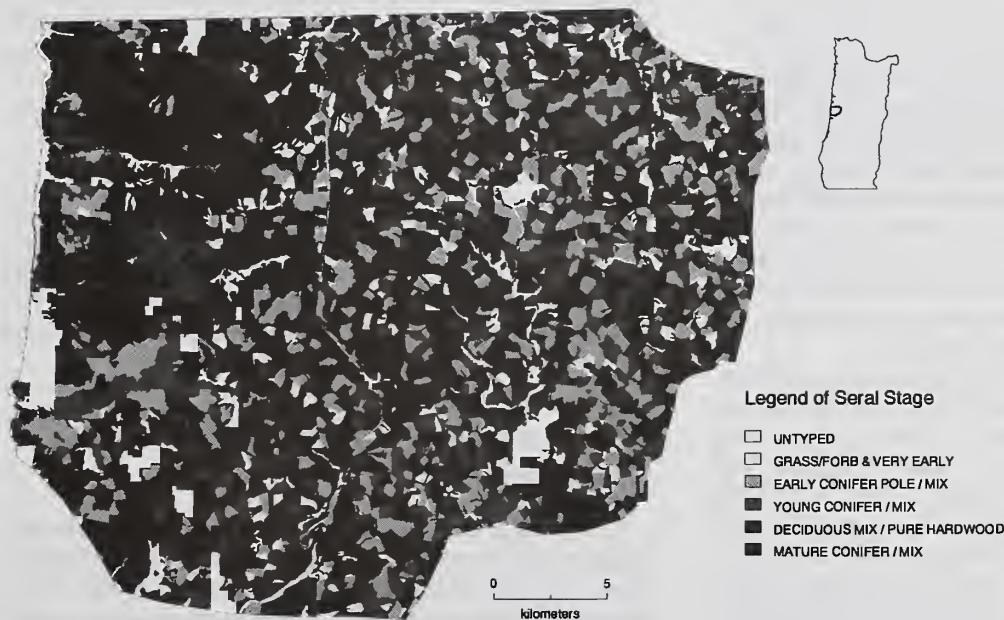


Figure 2—Seral stage map for 1992 in the North Fork Siuslaw River area of the Federal Lands Assessment, created by Bush and others (1995), through interpretation of aerial photographs.

Young Coast Range forests may be more susceptible to fire than older forests because they revegetate rapidly to dense stands of shrubs and trees with large amounts of fine, interwoven foliage close to the ground. In contrast, pole and mature stands often have canopies elevated 10-30 m from surface fuels with gaps in the conifer canopy. Also, the fire giving rise to the young stand will have produced a large quantity of dead fuels (branches) that last several years in this environment before decomposing.

Under the present disturbance regime, harvest rotations in managed forests have been about 45-60 years on private forest lands and 60-70 years on government lands managed for timber.

This paper relies heavily on maps and syntheses of others. Most of this work describes age structures and fire characteristics from 1848 to 1951, the date of the last Tillamook fire. For the Coast Range fire regime, this is less than the intervals between most fires—clearly shorter than required to give a clear picture of the fire regime. Nevertheless, we believe this to be a reliable description of the broad outlines of the fire regime for two reasons. It is supported by two unpublished theses by Peter Impara (in process, Ph.D., Oregon State University) on fire evidence in tree rings, and by Colin Long (M.S., University of Oregon) on fire evidence in 9,000 years of sediment in Little Lake. Also, given its environmental setting, this fire regime description is consistent with better known fire regimes in similar and different environmental settings in the Pacific Northwest, as previously discussed. Future work will help refine this description, but will probably not change it greatly.

The amount of old-growth forest in the Oregon Coast Range has changed dramatically. Under the historical fire regime, Teensma and others (1991) estimate old-growth covered 40 percent and 46 percent of our study area in 1850 and 1890, respectively. In contrast, the FEMAT (1993) estimate of current old-growth is only 2 percent of the Coast Range.

Biodiversity

The large change in stand age distribution probably has had significant consequences in the Oregon Coast Range. Considerable data exists for evaluating differences in plant and animal communities between old-growth and younger forests. Plant species diversity (inverse of Simpson's index) is greater for old-growth in both the overstory (4 versus 6) and understory (40 versus 50) (Spies 1991). Mass of snags and logs (95 versus 39 Mg/ha) are also greater in old-growth forests than in young post-harvest and mature forests, but not greater than in young post-fire forests.

Regarding the association of warm blooded animals to old-growth forest in the Coast Range, 3 of 57 bird species were found to be "closely associated" and 11 of the 57 bird species were "associated" with old-growth forest (Ruggiero and others 1991). Of 16 mammals studied, 6 were found to be "closely associated" and 4 "associated" with old-growth forest.

Several species of salamander are more common in old-growth forests than in mature and young forest in the Oregon Coast Range (Corn and Bury 1991). Wood in streams (6-12 versus 1-6 pieces per 100 m), number of pools (5-16 versus 4-10 count per 100 m), and fish species diversity (1.5

versus 1.1, inverse of Berger-Parker dominance) are greater in watersheds less than 25 percent cut-over than in watersheds more heavily cut (Reeves and others 1993).

Some of the reduction in floral diversity may be caused by dominance by the strong competitors red alder and salmonberry (*Rubus spectabilis*). Conifer regeneration and growth rate are known to be reduced under canopies of these species and other plant species may be similarly affected. The large increase in edge density and decrease in interior habitat has greatly increased the suitable habitat for species that prefer edge and decreased it for those that prefer interior habitat.

Potential Approaches to Management

We outline an approach to management of this large landscape that weaves important characteristics of the natural disturbance regime and pattern into the present managed landscape (Baker 1994), with the goal of restoring some of the biodiversity of the natural landscape. This is not a design to return the whole Coast Range to the natural or pre-harvesting disturbance regime, which is clearly impractical. Prescribed fire should be considered as a component of new ecologically based management schemes.

Establish Reserves

Some reserves will be needed to bring the age distribution of the landscape closer to pre-cutting conditions, in particular to increase old-growth forest. As the desired age distribution is approached through much of this area, reserves could be converted to long-rotation silviculture.

Increase Patch Size

Management can create larger patches. Forest management on private land has created large areas of relatively young forest, whereas much Federal land with abundant small clearcuts of different ages contains a surfeit of edge habitat.

Increase Rotation Lengths

Private and state-owned timberlands will probably continue to be harvested at ages of about 45-60 years, while average historic fire intervals (and, thus, rotation ages) were 4 to 7 times this long. Managing Federal lands for final harvest at long rotations of 200-400 years would move the Coast Range toward a more natural distribution.

Accelerate Development of Old-Growth Characteristics

There would be many opportunities to speed up development of old-growth characteristics, since there is an abundance of forest 30-80 years of age and tree growth is fast. Recent work shows conifer diameter increments are generally less in plantations than in natural stands; this is probably due to higher stocking. Thinnings of young and

mature stands would yield timber while increasing the growth rate of residual trees. Releasing individual conifers and sites from heavy red alder and salmonberry competition that retards conifer regeneration and growth would have ecological benefits and increase wood harvest in the long-term.

Encourage Conifers in Riparian Zones

Several methods should be explored. Some studies of conifer response to reduction in salmonberry and alder competition encourage use of mechanical and chemical approaches. It may be possible to obtain conservation easements that allow planting conifers in riparian strips in the privately owned agricultural land that dominates much of the riparian zones of larger streams and rivers. A first step in this direction would be to establish a voluntary program with a theme such as partners in conservation in which landowners gain improved riparian zone and stream health and an attractive conifer stand, and agencies gain the right to manage the riparian zone for quality stream habitat. As a second step, governments could exchange timber receipts from up-slope areas or tax incentives for such conservation easements.

Monitor and Adapt Management

A plan that relies more on a dynamically managed ecosystem and less on reserves would require a thoughtful adaptive management plan (that is, frequently reviewed and updated to reflect new knowledge and management strategies). If it is not carried out, problems may not be caught until significant loss of values occurs, so a mechanism must be in place to safeguard against this. One such safeguard would be to specify in the plan that, if monitoring and appropriate course corrections fall below prescribed levels, then a system of reserves become effective within which further active management is precluded.

Fire was historically a part of creating and maintaining Coast Range ecosystems. Managers can incorporate selected aspects of the natural disturbance regimes and landscape patterns into the managed landscape in desired places, using steps like those we described. These disturbances can be combined in varying amounts and spatial distributions to create alternative management plans that restore characteristics of the natural patterns. Our approach incorporates some of the long-term dynamics of the natural Coast Range ecosystems, and relies less on reserves than the current Northwest Forest Plan (Espy and Babbitt 1994).

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Fire in Restoration of Oregon White Oak Woodlands

James K. Agee

Fire has influenced both the morphology of species and their distribution for millions of years. Prescribed fire may be necessary to meet ecological restoration objectives, but reintroducing fire is a complex task. Fire may have undesirable effects if it is reintroduced outside of its "historical range of variability," or where the ecosystem has undergone major shifts in species composition or structure due to fire exclusion. Oregon white oak or Garry oak (*Quercus garryana*) woodlands and their associated prairies are a good example of this problem (Griffin 1977).

Oak woodlands and prairies in the Pacific Northwest were burned frequently by Native Americans. Almost all the early travelers to this region (1820-1850) described the prairie areas as having been burned. The oaks, with relatively thick corky bark and the ability to crown sprout, were well adapted to these fires. Visitors in the 19th century remarked "...Country undulating...with beautiful solitary oaks and pines interspersed through it...but being all burned" (Davies 1980), and extensive fires that "...destroyed all the vegetation, except the oak trees, which appear to be uninjured" (Wilkes 1845). The intensity of these fires must have been low, considering that a fire-sensitive species, Idaho fescue (*Festuca idahoensis*), was a dominant grass in the understory of the oak savannas and adjacent prairies.

A question arises as to how regeneration of the oaks survived in the face of frequent fires. Without a clear adaptation to regenerate, oaks might disappear over time if burned annually. First, regeneration is not a primary concern with a tree species that lives 400 years and also sprouts from rhizomes. If the main stem is killed, many suckers may emerge from an oak root system, which may encompass an area exceeding 250 m². Seedling regeneration is not common. The effect of fire on the relative importance of seedlings in comparison with sprout regeneration for Oregon white oak is not well understood.

In 1989, the Washington Department of Natural Resources (WDNR) conducted a prescribed fire at Oak Patch Natural Area Preserve, which was established to preserve a Oregon white oak/snowberry (*Symporicarpos albus*) community in western Washington. After the fire, oak seedlings were observed in the area. They were associated with corridors where logs had burned at relatively high intensity, consuming much of the soil organic matter. A comparison of microsites where seedlings became established to sites where vegetative sprouts had emerged showed soil and floristic

differences. (Agee, unpublished data). Seedlings are found on more heavily disturbed microsites. Soil carbon and soil nitrogen are significantly lower around seedling locations. Both carbon and nitrogen are volatilized by fire, and the amount lost is an index to fire severity. The plant species around oak seedlings are typical of very disturbed sites: tansy ragwort (*Senecio jacobaea*), velvetgrass (*Holcus lanatus*), and fireweed (*Epilobium angustifolium*). Most of the sprouting shrubs at the site are more common around oak sprouts: woodland rose (*Rosa gymnocarpa*), serviceberry (*Amelanchier alnifolia*), salal (*Gaultheria shallon*), and Cascara buckthorn (*Rhamnus purshiana*). In this low severity fire regime, seedling regeneration may depend on the presence of high severity microsites.

A critical constraint to using fire in oak woodlands and prairies is the presence of alien species. Shrubby aliens such as Scotch broom (*Cytisus scoparius*) and Himalayan blackberry (*Rubus discolor*) have invaded these open communities. Fire can be used to reduce the spread of these invaders, but must be used very carefully. A single intense fire can reduce Scotch broom cover, but may encourage germination of the seed bank of Scotch broom, and at least temporarily reduce cover of native perennials such as Idaho fescue. A second fire, which will be much less intense, is necessary in 2-3 years, before the new Scotch broom plants are mature enough to flower. This double fire treatment can greatly reduce Scotch broom, but it is often difficult to get fire to spread through these fuel-limited microsites. Spot treatments, such as using a flamethrower in the winter when grasses are green and fire will not spread, can remove any residual Scotch broom plants missed by the double-fire treatment, but is labor-intensive.

Native plants such as camas (*Camassia esculenta*), which Native Americans harvested as bulbs for their flour, seem to flourish after burning, based on observations at The Nature Conservancy's Yellow Island Preserve and at the WDNR's Mima Mounds Natural Area Preserve. Endangered plants such as Curt's aster (*Aster curtis*) appear to increase after burning, so that fire may be an essential element in prairie restoration. Idaho fescue is more sensitive, at least after the initial more intense fire. At the Mima Mounds Natural Area Preserve, managers have collected fescue seed at the site, grown it as nursery plugs, and outplanted the fescue in heavily burned microsites. The first planting in 1994 has shown quite vigorous growth after the first season, suggesting that restoration and preservation of fescue prairie may be possible in the face of Scotch broom infestations. The prairie has been divided into blocks so that not all the area is burned in one fire. Sensitive and rare butterflies which depend on Idaho fescue during their larval stages may then be preserved at the local scale while other portions of the prairie are treated.

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In oak woodlands and prairies, we will not be able to eliminate alien species, although we can recreate the appearance of the historic plant communities. We may, then, be restricted to creating from more than function in woodland and prairie restoration where alien species already have a foothold.

Fire can be an important element of conservation biology plans, and fire is being used along with removal of competing conifers to restore some of the remaining Oregon oak woodlands (Cook 1996). But just because fire was historically present as a natural process in ecosystems is insufficient guidance for its use in the future. We may not understand fully the significant effects of fire: for example, the concentration of oak seedlings in severely burned microsites within a low severity fire regime. Alien species may create new competitive environments for native species, even though the reintroduced fire regime may mimic the historical fire regime. The structure of the system may have changed, so that the effect of a natural process like fire may be different now than in the past. These constraints may not preclude the use of fire, but they may require a comprehensive analysis of the ecological costs and benefits associated with the proposed fire regime: its frequency, intensity, extent, timing, and synergism with other disturbance factors. Agee (1993)

provides a more detailed account of the role of fire in the Oregon oak type.

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Fire Regimes and Restoration Needs in Southwestern Oregon

Thomas Atzet

The Klamath Province, straddling the Oregon and California border along the north Pacific coast, roughly forms a square between Coos Bay and Crater Lake, Oregon, to the north, and Eureka and Redding, California, to the south. It is recognized as geologically unique (Dott 1971; Orr 1992) and is the most floristically diverse province in the western United States (Whittaker 1961).

Unlike temperate ecosystems farther north, southwestern Oregon's Mediterranean climate interacts with a variety of two million year old geologic substrates and produces an array of habitats adapted to both marine and continental climatic regimes. Compared to more northerly regions, southwestern Oregon has a warmer, drier climate conducive to fire over a longer season. Until recently, fire, the main disturbance agent (table 1), has been frequent and of low severity, but the amount of high severity fire seems to be increasing.

Disturbance regimes, including fire (table 1), vary by elevation and "Plant Series," a taxonomy based on the potential climax species (Daubenmire and Daubenmire 1968). Table 2 displays elevational characteristics of each Series. Figure 1 schematically shows the Series in an east-west transect across the Province. Mountain hemlock, the highest in elevation (table 2) is also the least disturbed Series. However, fire is still the most frequently observed disturbance (29 percent). Table 3 displays the mean disturbance

characteristics of the Series. Note that in all but Tanoak, mean intervals are shorter than the number of years since the last disturbance, an indication that mean intervals are increasing.

In the post World War II era, an expanding road system, lighter chain saws, versatile vehicles, emphasis on the importance of forest resources, and the Cave Junction smoke-jumper base (operational in 1940) significantly increased the efficiency of suppression after 1940. Figure 2 illustrates the effectiveness of suppression after 1940. Table 4, the percent of the area burned by severity class, shows the average proportion of high severity fire is about 14 percent (except for the Longwood fire). The Longwood fire, which burned an interface area that missed three cycles of fire, burned 26 percent of the area at high severity, an indication that long-term suppression tends to increase the proportion of high severity fire.

Figure 3 illustrates the accumulation of basal area of trees per acre (by Plant Series) that has occurred since the 1940's. Fuel accumulation is a major factor contributing to the increasing probability of more high severity fires. Density management (thinning) and underburning are recommended to reduce fuel buildup, reduce stand susceptibility to insects and diseases, and reduce the probability of soil damage and erosion resulting from wildfire.

Table 1—Last major disturbance, by Plant Series.

Agent	Series							
	White fir (n = 296)	Shasta red fir (n = 40)	Port- Orford-cedar (n = 18)	Tanoak (n = 195)	Jeffrey pine (n = 31)	Douglas-fir (n = 175)	Western hemlock (n = 51)	Mountain hemlock (n = 14)
Percent of plots								
Fire	56	48	72	74	68	72	45	29
Human	29	18	17	17	10	22	37	21
Wind	8	13	0	2	16	2	14	0
Disease	2	5	11	4	3	2	2	14
Erosion/soil creep	0	0	0	1	0	0	2	0
Ice/snow	1	8	0	0	3	0	0	21
Insects	1	0	0	0	0	0	0	0

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Cross Section of the Klamath Province
(Showing the schematic relationship among the plant series)

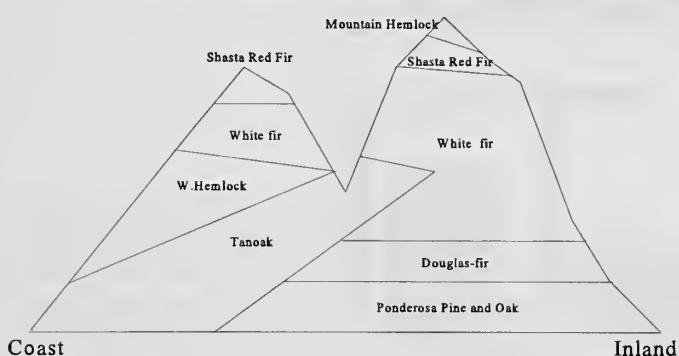


Figure 1—West-to-East cross section of the Klamath Province from Brookings, OR (Coast) to Redding, CA (Inland).

Table 2—Mean elevation of the Plant Series.

Plant series	Mean elevation	Standard deviation	Range
Whole Province	3,638	1,390	200-7,600
White fir	4,565	753	2,000-6,600
Shasta red fir	5,712	1,156	4,200-7,500
Port-Orford-cedar	3,876	872	1,800-4,800
Tanoak	2,394	789	200-3,800
Jeffrey pine	3,187	1,346	1,200-6,000
Douglas-fir	3,033	1,039	1,500-6,000
Western hemlock	2,740	1,094	1,600-4,600
Mountain hemlock	6,500	1,780	5,800-7,600

Table 3—Mean disturbance characteristics of the Plant Series.

Plant series	Mean age	Years since last disturbance	Mean interval
White fir	213	64	25
Shasta red fir	214	56	40
Port-Orford-cedar	419	129	50
Tanoak	243	58	90
Jeffrey pine	282	73	50
Douglas-fir	230	76	30
Western hemlock	281	63	65
Mountain hemlock	313	67	115

Table 4—Percent of area burned by severity class (Siskiyou National Forest).

Severity	Silver ¹	Silver ²	Cedar camp ³	Cedar camp ⁴	Galice ⁵	Longwood ⁶
High	12	11	15	13	17	26
Med	33	35	19	28	34	43
Low	55	54	66	59	49	31

¹Inside the Kalmiopsis Wilderness. The Silver fire area has a "natural" periodicity of 50 years.

²Outside the Kalmiopsis Wilderness. The Silver fire burned in 1987.

³Average severities for all the Cedar Camp fire that burned in 1937.

⁴Average severities for the areas that reburned during the Silver fire.

⁵The Galice fire burned in 1987 in a low elevation area not subject to intense suppression.

⁶The Longwood fire burned in 1987 in a populated area where suppression was intense.

Acres Burned Siskiyou National Forest

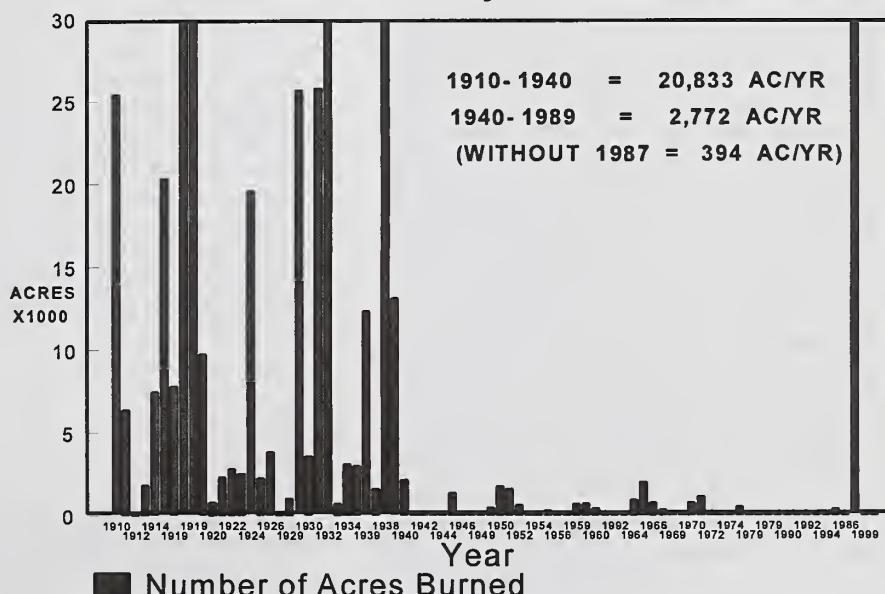


Figure 2—Acres burned by year on the Siskiyou National Forest.

Existing & Recommended Tree Basal Area by Plant Series (Applegate Area)

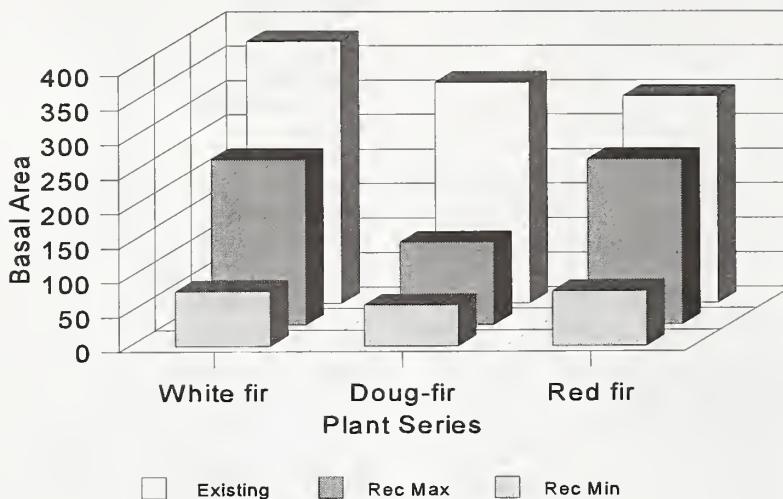


Figure 3—Basal area buildup in the Applegate area, showing existing, recommended maximums (Rec Max), and recommended minimums (Rec Min).

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Restoring Fire to Mixed Conifer Forests in the Northern Cascades

T. J. Leuschen

Many of the ponderosa pine (*Pinus ponderosa*) mixed conifer stands in the Methow Valley of north-central Washington have developed understories of Douglas-fir (*Pseudotsuga menziesii*) as a result of fire exclusion. Most of the forest floor has not yet become cluttered with dead woody fuel. Instead, the live biomass has increased and created more ladder fuels (branches near enough to the ground to carry a surface fire into the crowns). Consequently, crown fires can be initiated by fires of lower intensity. There is an increase in dwarf mistletoe (*Arceuthobium* spp.), root rot, and other associated pathogens. Our challenge as land managers on the Okanogan National Forest is to reduce the tree biomass and stems per acre and adjust species composition to more historic levels while restoring fire to these stands.

Clearcutting and other regeneration harvest methods have been selected in some stands. The fire history for these areas was determined to provide both guidelines for fuels treatment alternatives and indicators of what Coarse Woody Debris (CWD) levels are appropriate. Past practices called for felling of small unmerchantable trees called whips. We now leave whips standing and kill them when we burn. This makes them available for wildlife use, and will contribute to desired CWD loadings in the future.

A similar procedure is followed in areas where partial cutting has been selected. First, fire history is determined. Then desired conditions are developed based on the fire history and ecotype (site type). These desired conditions become objectives for the stand, specifically stand density, species composition, and CWD levels. These objectives are then used to develop the burn prescription.

The development of the burn prescription considers the time of year that wildfire typically occurred in the stand. This helps determine the appropriate intensity of fire to prescribe. Duration of flaming and smoldering stages of burning are important considerations for fire effects. In some cases, burns have been ignited under damp conditions, with subsequent ignition of unburned fuel concentrations during a dryer period. These have been very successful in achieving more random fire effects. Other considerations are risk of fire escaping or smoke intrusions. How good are containment lines? Is mop-up necessary to reduce risk of escape or smoke problems?

On one 200 acre unit, the logging method used was over-story removal. In addition, it was planned for pre-commercial thinning. The concern from a fuels standpoint was the slash created by thinning. The thinned trees were 30-40 feet tall and 3-6 inches in diameter. Following the harvest, a field review produced a new plan. The saplings and poles were determined to be undesirable for future crop trees due to stagnated condition and presence of dwarf mistletoe. We decided to use prescribed fire to kill the present stand, leave the mature overstory trees for seed source, create a good seedbed with fire, and begin to restore fire to the ecosystem.

Fire was ignited on June 24, 1993, by aerial ignition. First a helitorch (a device suspended from a helicopter which dispenses a burning petroleum solution onto the treatment area) was used to establish a good, burned-out control line below the road, and fire lines were ignited by hand. A sphere dispenser (a helicopter-burn device that drops small incendiary devices) was then used to ignite the remainder of the unit. All weather and fire conditions were well within the burning prescription. Humidities during ignition ranged from 46 to 60 percent. The humidities dropped to a minimum of 25 percent after ignition was completed. Temperatures ranged from 50 to 70 °F., and wind speeds ranged from 0 to 8 mph. Fine fuel moisture ranged from 6-9 percent, with flame lengths averaging 5 feet. Fire behavior was primarily a creeping ground fire with 4-8 foot flame lengths in heavier fuel concentrations. More torching occurred throughout the day as the relative humidity dropped. There were only a few short-range spots, and these were contained immediately by holding crews.

As a result of this burn, the desired mortality of saplings and pole-size trees was accomplished. Some additional felling of surviving small trees will be needed. Site preparation for natural regeneration was accomplished. There was good retention of the seed trees. Not all existing snags were consumed, and more snags were created by the fire. A few openings were created, and other existing ones were enlarged. While five acres were planted, natural regeneration is becoming established over most of the area.

The conclusions reached as a result of this project are that prescribed fire was successful in killing the majority of the undesirable understory trees. Additional thinning may be required. The large diameter ponderosa pine and Douglas-fir seed trees had adequate survival, and natural regeneration appears to be adequate. This application of several ignition methods, combined with mechanical treatments such as felling of some understory trees, was a highly successful project. We restored the desired conditions, creating opportunities for subsequent maintenance using low intensity, non-lethal fires.

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Applying Stand Replacement Prescribed Fire in Alaska

Larry A. Vanderlinden

Stand replacement prescribed burning has been applied in Alaska on several occasions. Based on that experience, perspectives can be provided, issues can be discussed, and keys to success can be identified that are applicable to stand replacement prescribed burning activities in areas outside Alaska.

There are approximately 220 million fire-prone acres in Alaska. Suppression of wildfires on a widespread basis has been effective only within the past 40 years. Between 1982 and 1984, Interagency Fire Management Plans were implemented that are still in effect. The intent of these plans was to reduce suppression costs, and to allow land managers greater latitude in making suppression decisions that were consistent with resource management objectives. The plans provide for a range of suppression responses, from aggressive suppression of fires threatening life and property to surveillance of fires in remote areas that do not threaten areas requiring protection. Approximately 65 percent of the fire-prone acreage on State and Federal lands in Alaska is in a "surveillance suppression" response category.

Although not a widely used practice in Alaska, prescribed burning has been utilized as a hazard reduction and resource management tool by the Bureau of Land Management, National Park Service, Fish and Wildlife Service, USDA Forest Service, and State of Alaska.

Background on Alaska

Summer in the taiga zone of the boreal forest ecosystem in Alaska is characterized by a short growing season and long daylight hours. Cold soils with discontinuous areas of permafrost and low decomposition rates are prevalent. Fire and flooding are major forces shaping the ecosystem and the vegetation mosaics in the taiga zone. Historic fire intervals are commonly 60-200 years. Stands of black spruce (*Picea mariana*) are common on poorly drained sites and stands of white spruce (*P. glauca*) are common on better drained sites. Birch (*Betula* spp.) and aspen (*Populus tremuloides*) are abundant in early to mid-successional stages of forest development. Alder (*Alnus* spp.), willow (*Salix* spp.) and ericaceous shrubs (heath) are common in the understory with a moss layer and lichens on the forest floor. Many forest stands in the taiga zone have limited or no commercial value. Wildlife, recreation, and subsistence resources for native peoples are often primary resource values.

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Precipitation is less than 15 inches a year, and in many areas is under 10 inches a year. Because of the low rainfall and frequent presence of frozen soils, spruce in the taiga zone are often moisture-stressed. Dead branches, especially in black spruce, commonly remain on the tree and extend to the ground. Consequently, even fires of lower intensity can torch out or climb into the canopy. Fire behavior in black spruce is characterized by a slow rate of spread with relatively high intensity. Short range spotting is common. The primary carrier of fire is the surface fuels. During extended dry periods, white spruce stands will burn with characteristics similar to black spruce.

Perspectives on the Use of Fire

The USDI Fish and Wildlife Service utilizes fire as a resource management tool on National Wildlife Refuges throughout the United States. The National Wildlife Refuge system in Alaska encompasses 16 refuges and 77 million acres. The Tetlin National Wildlife Refuge, at 724,000 acres, and the Kenai National Wildlife Refuge, at 1.7 million acres, are the only two road-accessible refuges in Alaska (fig. 1). A refuge management purpose common to both refuges is "to conserve fish and wildlife populations and habitats in their natural diversity." In Alaska, fire often plays an important role in supporting this purpose. Both Tetlin and Kenai refuges have stand replacement prescribed burn plans in place. In terms of planning and implementation of those burns, there are significant differences between the two refuges.

Tetlin

The Tetlin National Wildlife Refuge is relatively remote, and is located in the eastern interior of Alaska. Less than 3,000 people live within a 50 mile radius of the refuge. Although public use is high along the highway corridor on the north side of the refuge, public use is relatively low on portions of the refuge away from the highway. In part because of the frequent occurrence of large lightning-caused fires in interior Alaska and adjacent Canada, the public attitude towards smoke from forest fires is very tolerant. The only local news media is a bimonthly newspaper. The prescription latitude for burning on the Tetlin National Wildlife Refuge is relatively wide, with long dry periods common. There are routinely one to several potential windows of opportunity to accomplish prescribed burns in a given season.



Figure 1—Two National Wildlife Refuges in Alaska.

Kenai

The Kenai National Wildlife Refuge is located near the southcentral coast of Alaska on the Kenai Peninsula. In contrast to Tetlin, it is a premier recreation destination for tourists, with high public use. More than 300,000 people live within a 50 mile radius of the refuge, including the city of Anchorage. Lightning-caused fires and large fires occur infrequently on the Kenai Peninsula, and the public is very intolerant to the appearance and impacts of smoke. News media within 50 miles of the refuge include numerous radio stations, TV stations, and newspapers. The prescription window for burning on the Kenai National Wildlife Refuge is relatively narrow. Humidities are higher on average than in interior Alaska because of the marine influence. Smoke management constraints include a restriction on burning on weekends, minimum ventilation factors, and restrictions on smoke transport direction. Recreational uses late in the season have priority over prescribed burning. As a result, there may only be a single opportunity or no opportunity to accomplish prescribed burns in a given season.

Prescribed Burning Accomplishments

On the Tetlin National Wildlife Refuge, a 5,800 acre stand replacement prescribed burn was accomplished in 1993. Goals were twofold: to enhance the vegetation mosaic and vegetative diversity and to provide for the collection of research data on fuel consumption and fire behavior. Ignition was accomplished entirely by air, using a PREMO aerial ignition device dispenser. Natural barriers were used for containment lines, and no holding crews or holding action were required after ignition. The cost was less than \$1.50 per acre.

On the Kenai National Wildlife Refuge, the 7,000 acre Mystery Creek Burn has been planned for the past five years, but has not been implemented. Goals of this burn are:

to enhance habitat conditions for wildlife and to provide a fuel break adjacent to a forest of beetle-killed white spruce. Planned ignition method is by helicopter (using a helitorch), with some follow-up ignition on the ground using drip torches. An existing road, gasoline right-of-way, and constructed control lines will be used for containment. Line holding action and mop up will be required on the ground to insure containment. Costs are anticipated to be relatively high—between \$5.00 and \$35.00 per acre. A determinant in the variability in cost is whether weather and fuel conditions allow the entire unit to be burned in one or two burning periods, versus execution of several smaller burns over an extended time frame.

Stand replacement prescribed burning in Alaska has the potential to become more prevalent. The state of Alaska currently has three stand replacement prescribed burns in various stages of planning. There are additional stand replacement burns planned at both the Tetlin National Wildlife Refuge and the Kenai National Wildlife Refuge.

Issues

There are several issues that could affect the ability to implement stand replacement burns in Alaska. The first issue is cost. Stand replacement burns in many cases are expensive to implement. Funding uncertainties have increased in this era of shrinking budgets and downsizing. At the same time, suppression costs in many areas are spiraling upward. While landscape scale prescribed burning can be expensive up front, burning at landscape scale does help to reduce the per acre cost. Furthermore, it has the potential to save money in the long run by improving forest health and by creating mosaics which can help reduce the threats, and expense of, suppressing catastrophic fires.

Smoke management is an issue that is becoming increasingly important. Currently, quality regulations in Alaska in general are not very restrictive with regard to prescribed burning. However, Alaska is on the verge of implementing air quality regulations which establish an emission fee of \$5.07 per ton of assessable emissions. There is still a question on applicability to open burning of vegetation. If emission fees are assessed, it will greatly increase the costs of landscape scale prescribed burning, and could adversely impact implementation of plans. The 1993 prescribed fire on the Tetlin National Wildlife Refuge provides a good case in point. Fuel consumption on that project was determined to be 20.3 tons per acre, or 117,740 tons for the 5,800 acre burn (Ottmar, personal communication). An estimated 1,766 tons of particulate would be produced from the fire for an assessed emission fee of \$8,954 (Hardy, personal communication)—an emission factor of 30 lb/ton was used for this estimate. This emission fee would double the cost of burning—increasing the base cost of \$1.50 per acre to over \$3.00 per acre. Safety is another issue. Stand replacement burning over longer time frames and on a larger scale can increase risks of something going wrong, particularly with regard to unforeseen weather events. Safety of personnel implementing burns and the safety and protection of the public cannot be compromised.

Federal policy mandates land manager responsibility to insure that sufficient contingency suppression forces are

available on a daily basis when a prescribed fire is burning. With a decreasing national pool of suppression personnel, increasing suppression demands nationally, and increased interregional movement of suppression personnel to meet the national needs, it becomes more difficult and complicated to insure availability of contingency forces. This situation is exacerbated by the multiple burning-period timeframe of landscape scale burning projects. It is not usually financially feasible to insure personnel availability by paying for standby firefighters prior to development of a need for suppression action.

Keys to Success

Despite the obstacles, stand replacement prescribed burning can be successful. Keys to success include planning, public education, interagency cooperation, and research.

Good planning is essential. Risks must be identified and mitigated, burn objectives must be established that can be reasonably attained, contingency planning must be addressed, and safety must be emphasized.

Public education is important. If the public is not supportive, it becomes exceedingly difficult to execute landscape scale prescribed burning. Public support cannot be developed overnight. A concerted effort must be made to garner public support through outreach to the schools and the media and through public involvement in the planning process.

The USDI Fish and Wildlife Service has had success implementing a school curriculum on the "Role of Fire in Alaska." If the public is informed of and involved in the planning process, they are more likely to become stakeholders in the outcome and thus to support the action taken. Media coverage of prescribed fire activities should be encouraged; it is an invaluable opportunity for land managers to highlight and publicize burn objectives, the role of fire in the ecosystem, and the agency's fire management program in general.

Interagency cooperation and support is necessary to successfully accomplish landscape scale stand replacement prescribed burning. Incentives for cooperation include the increasing focus on ecosystem management by various agencies, the limited contingency suppression forces available from any one agency, and the increasingly sophisticated training and experience required for using prescribed fire. Agreements need to be in place to allow the sharing of local and regional fire control equipment and forces from various agencies. There may be opportunities to reduce project costs by utilizing aircraft with low contract rates from other agencies and also if cooperating agencies absorb some of the costs of resources they provide. Invaluable experience which can benefit fire management programs for each agency involved can be obtained and shared by assigning personnel between agencies.

Research is another important facet of successfully implementing landscape scale prescribed burning. With the inherent risks of using fire as a tool, managers need to be able

to effectively explain and defend their actions to an often skeptical public. Research is needed in many areas to clarify the role of fire in the ecosystem. Research projects must be designed that put useful information in the hands of resource managers to ease decisionmaking, planning, and attainment of desired effects and to increase public support.

The success of the stand replacement prescribed burning noted on the Tetlin National Wildlife Refuge was aided by several factors. The burn plan was smoothly implemented. Media coverage was encouraged, newspaper articles were written before and after the burn, and a television station reporter was allowed access to the operation. Other agencies that cooperated with the USDI Fish and Wildlife Service on the project were the USDI Bureau of Land Management and the State of Alaska. Research scientists from both the Intermountain and Pacific Northwest Research Stations, USDA Forest Service, collected data on fuel consumption and effects of heat on organic soils that are part of two national research projects.

Conclusions

In conclusion, the USDI Fish and Wildlife Service has had successes and failures in implementing stand replacement prescribed burning in Alaska. Due to the remote location of much of the public lands and to the successful implementation of interagency fire management plans that provide for a range of suppression responses in Alaska, there is little need for widespread application of stand replacement prescribed burning. However, the continued exclusion of fire from private lands and their adjacent public lands, and the difficulty and risks associated with implementing prescribed burning of any type in those areas are sources of increasing concern.

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Integrating Fire Management Into Land Management Planning for Westside Forests

Peter D. Teensma

Fire management's integration into land management planning is critical to the successful management of nearly all wildland ecosystems, including westside forests, which lie west of the Cascade crest in Oregon and the northern coastal ranges in California. Restoration and maintenance of fire as an ecosystem process is critical to retention of biological diversity and ecosystem sustainability. Knowledge of the natural roles of fire across the landscape, the effects of wildfire and prescribed fire, and the levels of risk of large-scale, high-severity fire, as well as the effects of fire exclusion must be incorporated into all scales of land management planning and assessment. Fire management planning must become an element of land management planning, rather than remain separate from (and typically undertaken subsequent to) land management planning. All aspects of fire management—fire suppression, prescribed fire, fuels management, smoke management, fire planning, modeling, risk and hazard analysis, fire history and fire ecology—will need to be considered by interdisciplinary teams during land management planning.

Successes and Failures

Progress toward the integration of fire management into land management planning in westside forests of the Pacific Northwest has been slow, but ongoing over the past 20 years. Recent assessment and planning efforts, such as the hazard analysis done by Agee and Edmonds in the Draft Final Recovery Plan for the Northern Spotted Owl (1992), the Northwest Forest Plan (USDA Forest Service and USDI Bureau of Land Management 1994), and the revised Federal guidebook on Ecosystem Analysis at the Watershed Scale (USDA Forest Service 1995) demonstrate some success and also some failures of the needed integration.

Efforts to integrate fire management into land management planning date back at least to the early 1970's, when the Fire in Multiple-Use Management Research, Development and Applications (RD&A) Program was initiated by the USDA Forest Service, Intermountain Research Station in Missoula, MT, to assist land managers. The message then was virtually the same as it is today—fire managers and land managers share three critical needs to support the attainment of land management objectives:

1. An understanding of the role of fire as an ecosystem process.

2. Integration of knowledge of fire's role with the management objectives of a specific land unit. Emphasis is on the

need to vary land management objectives based on fire's role and the need to vary fire management based on today's land management objectives.

3. Recognition of the difficulties in limiting damages from wildfire and, more specifically, the damage from suppression actions.

By the 1970's, land managers and government regulators had become concerned about the environmental impacts of a highly effective fire suppression policy and about the rapidly escalating cost of suppression. There was also a concern that managers were not listening to those with knowledge of the ecological role of fire and of its beneficial uses.

It may seem discouraging that we are attempting to resolve some of the same issues and problems 20 years later. In fact, the merits of using fire to maintain forest health in northern California and southern Oregon were heavily debated in the early 1900's (Pyne 1995).

The Federal Wildland Fire Management Policy and Program Review (USDI and USDA 1995) addresses the need to integrate fire into the planning process. It also mandates that the Federal agencies will develop and transmit a clearer message about the role of fire and the consequences of attempts to exclude it. Land management agencies may be required to compare risks and costs associated with attempted fire exclusion versus risks and costs of using fire and fuel management treatments in the context of meeting resource management objectives.

The essential question remains, "How do we integrate fire into land management planning?" A very good example of bringing the integration of fire into planning at a local level has been shown by recent progress in modeling fire regimes of western Oregon. Additional progress has been made at developing tools to model risk using stochastic simulation of fire events, and at communicating the expected results of fire management-related considerations using decision-tree analysis. Such analysis can indicate the probabilities of various outcomes given a series of decisions.

The Northwest Forest Plan is an example of a contradictory attempt to include fire in land management planning. While knowledge of fire's role was included in the scientific assessment from the beginning, fire management involvement was not originally considered necessary for the planning process. The Northwest Forest Plan consists of three completed sets of documents: (1) The Forest Ecosystem Management Assessment Team Report (FEMAT) (USDA Forest Service and USDI Bureau of Land Management 1993), (2) The Final Supplemental Environmental Impact Statement (FSEIS) (USDA Forest Service and USDI Bureau of Land Management 1994), and (3) The Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl (published with a standards and guidelines document) (ROD) (USDA Forest Service and USDI Bureau of Land Management 1994).

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Some reviewers say that fire management is not integrated into the Northwest Forest Plan, while others state that the information on fire management is too integrated, and that it would be better to put all discussion and analysis of fire management into one section. Much fire-related information is located throughout the FSEIS nonetheless. Some of the particularly effective sections include:

- The description of the alternatives
- The ecosystem viability assessment
- The air quality analysis
- The fire management standards and guidelines
- The ecological principles for management of late-successional forests
- The Late-Successional Reserve standards and guidelines
- The northern Spotted Owl recovery plan standards and guidelines

Integration of information alone does not necessarily bring about better application. The actual implementation of the Northwest Forest Plan has been a greater barrier to the integration of fire management. "Watershed Analysis," now known as "Ecosystem Analysis at the Watershed Scale" has been focused on aquatic and hydrologic issues. Broad standards and guidelines (for example, for coarse woody debris retention) were defined only on an interim basis until they could be more locally defined in Planning Province Analyses or Watershed Analyses. On the other hand, results from Late-Successional Reserve Assessments have persuaded the Regional Ecosystems Office to grant certain area-specific exemptions to the Forest Plan standards and guidelines. This has enabled the implementation of a number of silviculture and fuels management projects. Similarly, Adaptive Management Area Plans have discovered and are supporting fire management needs that appear, at first, to be contrary to the goals of the Forest Plan.

Some procedures and tools recommended to help field units integrate fire into the Watershed Analysis planning process have been accepted by the Regional Ecosystem Office. For example, the Fire Disturbance & Risk Module can be summarized in the following steps:

1. Describe the natural fire regime. What is the role of fire (both historical and current)?
2. What are the vegetation conditions, including live and dead fuels, and the effects of fire exclusion?
3. What are the probabilities of fire occurrence, by size and intensity?
4. What are the likely consequences of these fire events?
5. What are the composite risks to the resources being managed?
6. What potential mitigation measures can decrease the risk (for example, fuels modification, or changes in fire suppression strategy or response)?
7. What are the biological (species and function) and landscape (ecosystem and process) needs for prescribed fire?
8. What are the consequences of continued fire exclusion or attempted fire exclusion (for example, deferred events)?

This basic framework for the module can be used in any scale of analysis and planning beyond Watershed Analysis. The Northwest Forest Plan was a large project done in a short period of time. Perhaps if it had been initiated after the final Federal Wildland Fire Management Policy and Program Review, it would have included much more emphasis on risk

reduction. Nonetheless, we must recognize that planning is a continual process. Broadscale plans must be adapted to local needs by another tier of planning. In this "bottom up" approach, projects are planned from the local land management plans. Within this hierarchical model, all of these planning tiers can, and do, undergo revisions and amendments.

Conclusions

Fire as an ecological process is rarely a single, one-time event. Moreover, when fire is deliberately used as a tool in restoring maintaining ecosystems, fire is often applied repeatedly (and always with great care when applied after a prolonged exclusion). When fire is integrated into land management planning, it frequently requires a change in the thought processes of resource managers. This is also not a single event. Like fire's application as a tool, incorporating fire management into land management planning will also require great care and diligence. The integration process must be repeated with each assessment, with each plan, and with each project.

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Epilogue



Can We Restore the Fire Process? What Awaits Us if We Don't?

R. Gordon Schmidt

This paper's title—"Can we restore the fire process? What awaits us if we don't?"—represents an ecologist's view of the world. I submit that this view is unrealistic. The first clause uses the term "restore" which implies reestablishing the fire process of the past. The second phrase uses the absolute term "don't" which implies that we can. Both of these phrases are too determinant for me. The 1995 International Conference of the Society of Ecological Restoration slogan challenges us to "Take a Broader View." If we do that we can see the real challenge.

Restoring the Fire Process?

Go Back? No! The objective of the symposium is to "examine the interaction of science and human values into sustainable human-environment relationships." I would suggest that "restoring" fire, that is to say, going back to the way it was historically, is a fool's errand because it is NOT sustainable.

It is not sustainable for three reasons: social demand, economic considerations, and the changing nature of the ecological system itself. Society will continue to demand services such as fire protection, which will preclude restoration in large areas, for instance near the ever-expanding suburban-wildland zone. Given the human values that interact with every ecosystem on earth, human demand will not allow us to return to the past. Humans will always demand that in some places, and at some times, we try our best to defeat nature and exclude fire from an ecosystem. And I predict we will be successful.

Further, we cannot afford to do all the projects necessary to restore fire everywhere it is needed. Money is not available to undertake all possible projects. Prioritization is required to make any significant progress.

The changing ecology (such as global climate change) requires that restoration efforts focus on a moving target. We cannot restore what has yet to be determined. So, the "broader view" leads us to a different task.

What Happens if We Don't?

If we take a broader view of this statement, it implies that we can. Here again I think human demand for values will not allow us to restore past regimes. Further, nature may have something to say about whether we can or can't. For example, global climate change. What ecosystems will result

from global climate change? What fire regime? How can man restore a process (fire regime) that is yet to be determined?

So, let's reword the task. "How do we assure that the effects of fire (as an ecosystem process) are replicated in ecosystems in a way that is socially and environmentally successful?"

Do we need to use fire? An unequivocal YES! We don't have to use fire because fire is magic, or because some deity will punish us if we don't. (However, if you listen to some evangelists on the matter you might think that the case.) We must use fire because we have no way of effectively replicating its effects. Fire effects generally come in three forms, chemical, physical, and thermal.

- Chemical effects of fire, such as nitrogen release, can successfully be approximated by the application of fertilizers or other chemicals to a site. We generally know enough about the chemical effects of fire so as to be relatively successful at replicating them.
- Physical effects of fire, such as biomass consumption, can be successfully replicated as well. In fact, regeneration timber harvesting (such as clearcutting) generally finds its conceptual silvicultural basis in replicating a stand replacement fire. We are becoming sophisticated enough now to actually prescribe amounts of material to leave on site in an effort to more closely replicate fire effects resulting from incomplete combustion.
- However, thermal effects of fire are another story. Thermal effects are virtually impossible to replicate at any scale in any ecosystem. Not only that, but thermal effects show tremendous variation over an area. Nature, when applying fire, makes a decision at every juncture, at every plant, at every point, how much thermal effect to apply. Take a tree, for example; the thermal effect can vary across the full spectrum from no effect to death, and anywhere in-between. The randomness of the thermal effects resulting from the application of fire, either prescribed or natural, are impossible to replicate. Further, this randomness is (in all likelihood) an important element of fire effects in ecosystems.

Can We Use Fire in an Applied Sense?

Yes, I think we can, but not in an effort to replicate the past. Rather, I believe that the real challenge for fire managers and fire ecologists is in designing the fire regimes of the future. We know that nature will define a fire regime for us. We also know that we will have a social demand placed on us to exclude nature's desire in many places.

So, how can we more fully understand nature's intent and integrate that with our desires? What policies do we put in

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place today that allow natural processes to be able to be unimpeded in the future? These are the critical questions. A perspective of looking into the future is more beneficial than one of replicating the past.

What if we don't? Our challenge on the planet has always been to adapt to the ecosystem. It has been very ineffective to challenge ecosystem process because nature is difficult to contend with, she has all the energy, all the knowledge, and we can't counterbalance her ability.

If we don't figure out how to adapt our practices to take small advantages of utilizing some ecosystems—either for social values such as living or as social demands such as products—then the use-opportunity will be denied by nature. Fire will always be here. The question is what will

determine what type and what effects it will have in various locations.

In the long term, ecosystems with long fire-return intervals will encounter the same problems (for example, unacceptable wildfires) now confronting short-interval, fire-adapted ecosystems.

In the very long term, it makes no difference. A thousand years from now it will all be moot. Nature will allow whatever she will allow over the next thousand years. Humans may, if we're lucky, obtain some small benefit by being wise in our use of ecosystems for our values. Where we are going is undoubtedly different than anything we conceive of today.

It is our destiny to try, however. So we will!



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The 26 papers in this document address the current knowledge of fire as a disturbance agent, fire history and fire regimes, applications of prescribed fire for ecological restoration, and the effects of fire on the various forested ecosystems of the north-western United States. The main body of this document is organized in three sections: Assessing Needs for Fire in Restoration; Restoration of Fire in Inland Forests; and Restoration in Pacific Westside Forests. These papers comprise the proceedings from a general technical conference at the 1995 Annual Meeting of the Society for Ecological Restoration, held at the University of Washington, Seattle, September 14-16, 1995.

Keywords: fire ecology, fire regimes, forest restoration, disturbance, prescribed fire

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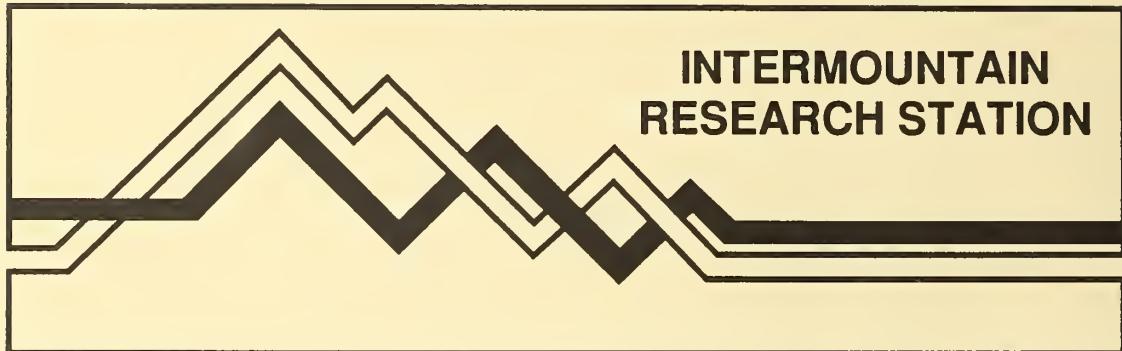
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